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EDITORIAL

In the Editorial to Volume XXI, issued as a whole in December, 1944, the Editors explained the reasons which had led them to take that step. The difficulties of publication have been even greater in 1945, manuscript has come in very slowly and it has been impossible within the year to complete even an instalment of Volume XXII. We have been able to combine Parts 1 and 2 of Volume XXII as a single issue, and enough material is now available to publish Parts 3 and 4 during the current year. Unfortunately exceptional difficulties of printing and publishing have also inevitably delayed the appearance of the Journal, but the Editors hope that from now onwards manuscript may come in more regularly and that with sufficient paper made available a return to quarterly or at least half-yearly numbers will soon be possible.

They would like to take this opportunity of thanking both contributors and subscribers for their patience during these wartime years and to express their keen desire for a return to normal publication during 1947.

Ronald G. Hatton.
T. Wallace.

EXPERIMENTS ON THE PRODUCTION OF TOMATOES IN THE OPEN

By WILFRED CORBETT

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SINCE 1940 the production of tomatoes in the open has become of considerable importance and the area devoted to this crop has increased in a remarkable manner. Although they had previously been grown in the open in Kent and in other parts of the South of England for many years, no experimental work appears to have been carried out in this country on this particular phase of tomato production up to the beginning of the present war. In 1941, therefore, experiments and trials concerned with various aspects of outdoor tomato production were started at the Glasshouse Demonstration Station, Wilmington, in Kent, and they were continued over four years.*

I. VARIETY TRIALS.

Trials of varieties for their suitability for crop production in the open were started in 1941. To be suitable for this a variety should be early maturing and give a high yield. The proportion of fruit picked green at the end of the season should be small, and the fruit should be of good shape, uniform in colour and firm after picking.

In 1941 five varieties were selected for an experiment set out in the form of a 5 by 5 Latin square. It was included in the National Trials of Outdoor Tomatoes organized by the Experimental and Research Station, Cheshunt. Each plot measured 30 ft. by 15 ft. and the plants were set out 18 in. apart, in rows 3 ft. apart, giving 100 plants per plot.

In 1942 a further experiment with nine varieties was carried out, the lay-out consisting of four blocks of nine randomized plots. The plots were of the same size as in 1941, but the plants were set out 15 in. apart in rows 3 ft. apart, thus giving 120 plants per plot.

An experiment similar to that of 1942 was carried out in 1943, using the same plots. Unfortunately the majority of the plants became infected with Enation Mosaic, which probably largely accounted for the low yield. A duplicate experiment was carried out at East Malling Research Station in 1943, in which the plots measured 25 ft. by 15 ft. with 100 plants per plot.

The crop yields obtained from the three years experiments are set out in Table I. From this it will be seen that two varieties, Earliest of All and Harbinger, were outstanding so far as early maturity is concerned, and they produced significantly higher yields than any of the other varieties during the first weeks of picking. At the other end of the scale, X-Ray and Ailsa Craig appeared to take longer to produce mature fruit. Of the remaining varieties Potentate was significantly earlier than most, and Market King was significantly earlier than at least three other varieties.

The differences in yields of fruit picked ripe were equally marked and, as might probably have been expected, the varieties giving high yields in the first weeks of picking generally gave the highest total yields of ripe fruit. In 1942 Earliest of All gave a significantly higher yield of ripe fruit than four of the other varieties, and in 1943 it produced the same result. Similarly, in 1942 and 1943, Market King gave a significantly higher yield of ripe fruit than four of the other varieties. The outstanding varieties in respect of yield of ripe fruit during the three years of the trials were Earliest of All, Market King, Early Market and Harbinger.

There was considerable variation in the yield of fruit picked green at the end of the season and the Standard Error was high, amounting, in 1943, to as much as 25·4 per cent. of the total

* For details of cultural operations and treatments the Appendix should be consulted.

yield. In general, however, the quantity of green fruit picked at the end of the season was less in the earlier than in the later maturing varieties.

The results indicate that four varieties, Earliest of All, Market King, Harbinger and Early Market, are all very suitable for outdoor production under the conditions of the trials. It should be stressed that tomato varieties do not always behave similarly on different types of soil, and climatic conditions also have a considerable effect. From general experience in Kent, however, the varieties mentioned have nearly always proved satisfactory.

TABLE I.

Tomato crop yields in Variety Trials 1941-43.

	1941.						1942.					
	% Yield of ripe fruit, picked by		Yield of ripe fruit. Tons per acre.	Green fruit.		Total yield. Tons per acre.	% Yield of ripe fruit, picked by		Yield of ripe fruit. Tons per acre.	Green fruit.		Total yield. Tons per acre.
	31st Aug.	8th Sept.		% of total yield.	Tons per acre.		31st Aug.	8th Sept.		% of total yield.	Tons per acre.	
Market King	6	27	17·3	23	5·1	22·4	11	33	18·1	28	7·0	25·1
Potentate	4	31	15·6	17	3·2	18·8	16	33	17·0	23	5·2	22·2
X-Ray	1	15	19·4	18	4·0	23·4	9	23	16·7	29	6·8	23·5
Earliest of All ..	—	—	—	—	—	—	19	48	19·3	11	2·5	21·8
Hundredfold	—	—	—	—	—	—	13	41	19·1	22	5·3	24·3
Ailsa Craig	—	—	—	—	—	—	9	23	19·2	27	7·3	26·7
Early Market ..	—	—	—	—	—	—	12	36	18·8	21	5·1	23·9
E.S.1.	4	21	13·9	38	8·4	22·3	—	—	—	—	—	—
Exhibition	1	21	15·7	20	4·0	19·7	—	—	—	—	—	—
Essex Wonder ..	—	—	—	—	—	—	11	31	15·1	31	6·9	22·1
Local variety from East Kent ..	—	—	—	—	—	—	13	40	16·7	27	6·1	22·7
Standard Error ..			0·56						0·73			
	1943.						1943 (East Malling).					
Market King	37	52	11·6	29	4·7	16·4	41	59	15·0	34	7·6	22·6
X-Ray	20	36	6·0	39	3·9	9·9	27	40	11·2	48	10·5	21·7
Earliest of All ..	44	58	11·0	25	3·7	14·6	48	68	16·3	26	5·7	22·0
Hundredfold	28	46	8·7	33	4·3	13·0	40	56	14·4	36	8·1	22·5
Ailsa Craig	27	45	7·1	42	5·1	12·2	34	53	15·7	31	7·1	22·8
Early Market ..	29	42	10·1	32	4·8	15·0	39	55	14·6	38	9·1	23·7
Harbinger	41	57	11·1	25	3·6	14·7	46	64	16·9	32	8·0	24·9
Vetomold	26	41	8·5	29	3·6	12·1	48	64	15·1	21	3·9	19·0
Radio	28	43	9·3	33	4·7	14·2	32	52	13·7	38	8·3	22·0
Standard Error ..			0·74						0·77			

II. PLANTING DISTANCE TRIALS.

Experiments on planting distance were carried out in 1941 and 1942. In 1941 it was not possible to use more than two rows of plots, each measuring 30 ft. by 15 ft. Five different planting distances were used, and it was possible to have three plots with plants set out at each of the different spacings, viz. : (1) single rows 3 ft. apart, with plants set at (*a*) 18 in., (*b*) 15 in., and (*c*) 12 in., apart in the row, and (2) double rows, i.e. rows alternately, 18 in., and 3 ft. apart, with plants set at (*a*) 18 in., and (*b*) 15 in., apart in the row. The variety used was X-Ray. The number of plants to the acre varied from 9,680 to 15,132.

In 1942 the experiment was conducted in four randomized blocks of six plots each, using the following distances : (1) single rows 3 ft. apart with the plants set at (*a*) 18 in., (*b*) 15 in.,

(*c*) 12 in. and (*d*) 9 in., apart in the row, and (2) double rows alternately 18 in. and 3 ft. apart, with the plants set at (*a*) 15 in. and (*b*) 12 in., apart in the row. The number of plants to the acre varied from 9,680 to 19,360. The variety was Market King.

It is reasonable to suppose that, within certain limits, the total yield per acre will bear a direct relationship to the number of plants set out. It is also reasonable to suppose that, within these limits, there will be an optimum planting distance, which it would not be economical to reduce, since the extra yield obtained by exceeding the optimum would not compensate for the extra cost of plants, labour, etc.

The combined results of the two years' experiments are shown in Table II. From this it will be seen that by increasing the number of plants per acre the yield is increased. The increase in yield in the single row plots is not proportionate to the increase in the number of plants ; thus, in 1941, an increase of 50 per cent. in the number of plants gave an increase of 21 per cent. in weight of ripe fruit picked, whilst in 1942 the increase in weight of ripe fruit was 19 per cent. for an increase of 50 per cent. in plant population, and only 32 per cent. for a 100 per cent. increase in it. The double row system, which gives more plants per acre at the same spacing in the row than the single row method, gave an increase in yield almost proportionate to the increase in the plant population in 1941, but in 1942 the increase was not so large.

TABLE II.

Crop yields at different planting distances.

Planting Distance.	No. of plants per acre.	1941. Yield of ripe fruit. Tons per acre.	1942. Yield of ripe fruit. Tons per acre.
1. *Single rows, 3 ft. apart.*			
Plants 18 in. apart in row	9,680	18·29	13·77
,, 15 in. ,, ,, ...	11,616	21·97	14·27
,, 12 in. ,, ,, ...	14,520	22·31	16·17
,, 9 in. ,, ,, ...	19,360	—	18·60
2. *Double rows, alternately 18 in. and 3 ft. apart.*			
Plants 18 in. apart in row	12,906	23·92	—
,, 15 in. ,, ,, ...	15,488	28·58	18·00
,, 12 in. ,, ,, ...	19,360	—	17·34
			S.E.=1·26

The desirability of continuing these planting distance experiments in 1943 was carefully considered, but because several factors govern the number of plants set out per acre, it was decided that no useful purpose would be served by continuing them. The principal factor which, in commercial production, governs the number of plants per acre is the row width necessary to carry out cultivations and spraying. When hand cultivation is employed, as is usual on small nursery and market garden holdings, a row width of 3 ft. is adequate ; but in large scale production, in which small tractors or horses are used for cultivating between the rows, a wider row spacing must be arranged, and it is quite usual to have rows as much as 4 ft. 6 in. and 5 ft. apart. The optimum distance apart in the row must depend on row width, but it would appear from the results obtained that for a 3 ft. row very little is gained by planting at less than 12 in. apart. It is also probable that even with a wider row spacing, e.g. 4 ft., or more, it would not be economical to plant at less than 12 in. apart in the row.

The double row system is not frequently used, nor can it generally be recommended, because of the difficulties of spraying and dusting for Blight control ; in bad Blight years the disease

would spread easily and quickly between the narrow rows of plants where it is so difficult to apply fungicides efficiently.

III. Manurial Experiments.

In 1941 a manurial trial to compare the effects of stable manure with, and without, the application of other fertilizers was laid out in the form of a 5 by 5 Latin square. From the analysis given in Table III it will be seen that stable manure without the addition of fertilizers tended to depress the crop; but in the presence of a complete fertilizer, i.e. one containing nitrogen, potash and phosphate, it slightly increased the yield, neither of these effects in themselves being significant. In both the absence and presence of stable manure, the complete fertilizer increased the crop yield, and the results may be regarded as significant.

Table III.

Ripe fruit. Tons per acre.

Treatment.	Nil.	Complete fertilizer.	Effect of complete fertilizer.
Nil	18·49	19·82	+1·33
Stable manure ..	17·62	20·56	+2·94
Effect of Stable Manure	−0·87	+0·74	

The plan of the experiment was changed in 1942 to a lay-out of three blocks of randomized plots to compare the relative values of different dressings of farmyard manure, and to ascertain the effects of added nitrogen and potash; all the plots received a dressing of a phosphatic fertilizer. The analysis in Table IV gives the overall results obtained.

Table IV.

Treatment.	Yield of ripe fruit. Tons per acre.	Increase over No Organic.
No Organic	17·17	—
Farmyard manure, 15 tons per acre ..	17·71	0·54
,, ,, 30 tons per acre ..	17·46	0·29

S.E. between No Organic and either rate of application of F.Y.M. = 1·03; between the two rates of application of F.Y.M. = 1·27.

Turning to the effect of the added nitrogen and potash, there was, as can be seen from the analysis in Table V, some sign, not significant, of an effect from nitrogen but none from potash.

Table V.

Treatment.	Tons ripe fruit per acre.	Effect of fertilizers.
No nitrogen	16·94	
Added nitrogen	17·99	+1·25
No potash	17·34	
Added potash	17·55	+0·21

S.E. = 0·43.

In 1943 the experiment was repeated, when plots which had received farmyard manure at the rate of 30 tons per acre in 1942 did not receive a dressing of bulky organic manure, so that any residual effect might be ascertained. Similarly, plots which had not received any bulky organic manure in 1942 were given a dressing of farmyard manure at the rate of 30 tons per acre. The results of this experiment are set out in Table VI, so far as the yield of ripe fruit is concerned.

TABLE VI.

Treatment.	Yield of ripe fruit. Tons per acre.	Increase over No Organic.
No Organic	13·58	
15 tons dung per acre	17·60	+4·02
30 tons dung per acre	16·74	+3·16
Residual dung	15·35	+1·77

S.E. between any F.Y.M. treatment=1·25; between any treatment =1·08.

From an examination of this analysis it will be seen that there was a significant response to dung at both rates of application. As to the residual effect, there was a marked increase in yield, but it did not reach significance. From comparisons between the effects of the two rates of applications of dung it would be incorrect to say that dung at 15 tons per acre was better than at 30 tons per acre.

There was no sign of response to fertilizers so far as yield of ripe fruit was concerned, as may be seen from Table VII.

TABLE VII.

Treatment.	Yield of ripe fruit. Tons per acre.	Effect of fertilizers.
No nitrogen	15·67	
Added nitrogen	15·95	+0·28
No potash	15·95	
Added potash	15·64	−0·31

S.E.=0·71.

The yield of green tomatoes appears to be increased by the application of dung in a much greater proportion than that of ripe fruit, as can be seen from Table VIII.

TABLE VIII.

Treatment.	Yield of green fruit. Tons per acre.		Effect of dung.	
	1942.	1943.	1942.	1943.
No Organic	5·03	2·84		
15 tons dung per acre	6·95	4·76	+1·92	+1·92
30 tons dung per acre	5·83	5·16	+0·80	+2·32
Residual dung		4·04		+1·20

S.E. 1942 experiment=1·03. S.E. 1943 experiment=1·08.

Added nitrogen also produced a significant increase of green fruit as may readily be seen from Table IX ; but added potash depressed the yield of green fruit in 1942, and gave no significant result in 1943.

TABLE IX.

Treatment.	Average yield green fruit. Tons per acre.		Response to fertilizers.	
	1942.	1943.	1942.	1943.
No nitrogen	5·18	3·89		
Added nitrogen	6·69	4·50	+1·51	+0·61
No potash	6·64	4·13		
Added potash	5·24	4·27	−1·40	+0·14

S.E. 1942 experiment=0·43. S.E. 1943 experiment=0·37.

It should be pointed out, however, that excessive applications of nitrogen are likely to produce plants with luxuriant growth, the fruits of which are generally small and slow to ripen.

Generally, the following conclusions may be drawn :

(1) The addition of farmyard manure at both 15 and 30 tons per acre has given a significant increase in yield of fruit picked ripe, and an even greater increase in fruit picked green at the end of the season.

(2) In the presence of farmyard manure there is some indication that added nitrogen is beneficial, and also produces a significant increase in yield of fruit picked green at the end of the season.

(3) When dung is present, added potash appears to be of little value in respect of either ripe fruit or of fruit picked green at the end of the season.

IV. THE TREATMENT OF OPEN LAND WITH FORMALDEHYDE.

One or two growers have carried out formaldehyde treatment of open land used for tomato production. Under glasshouse conditions the soil gradually becomes tomato sick ; partial sterilization is carried out to improve its fertility and, as a general rule, an increased yield is obtained. Accordingly, in 1943, an experiment was designed to ascertain whether formaldehyde would have any effect on the crop yield, and land that had been used for tomato production in the two preceding years was selected for the purpose. The treated plots received formaldehyde

TABLE X.

The effect of formaldehyde treatment. Yield in tons per acre.

	1943.		1944.	
	Formaldehyde.	No formaldehyde.	Formaldehyde.	No formaldehyde.
August picked	5·80	5·85	0·36	0·27
September picked	8·39	8·29	1·01	0·90
October picked	—	—	1·20	1·19
Total ripe fruit	14·19	14·14	2·57	2·36
Green fruit	5·13	4·92	8·35	8·17
Total yield	19·32	19·06	10·92	10·53

at a strength of 1 gallon commercial 38/40 per cent. formaldehyde to 49 gallons of water, at the rate of 50 gallons of the solution to 10 sq. yds. The experiment was repeated in 1944.

In both years the plants growing in the formaldehyde treated plots appeared stronger, and the foliage, which was of a darker colour, retained its good colour for a considerably longer period than did the plants growing in the untreated plots. The results of this experiment are shown in Table X. Despite the better appearance of the plants growing in the treated plots it will be seen that the formaldehyde treatment had no significant effect on the crop yield.

V. METHOD OF PLANT RAISING.

In raising tomato plants for planting in the open the seedlings are usually potted into 3 in. or 3½ in. pots or are transplanted into trays, generally 24 seedlings to a standard sized seed tray measuring 14 in. by 9 in. It seems reasonable to suppose that the seedlings transplanted into pots will produce more suitable plants for setting out in the open than those transplanted into trays ; for not only will they have a bigger root system and should get away more quickly when planted out, but the roots would not be damaged when this is done, as must happen with plants from trays.

To obtain information on this question an experiment was carried out in 1943, and was superimposed on the formaldehyde experiment described above. Two varieties were used, namely Market King and Earliest of All, half the plots being planted with plants from trays, and half with plants from pots.

From the analysis in Table XI it is readily apparent that there was a highly significant difference in crop yield in the first month of picking in both varieties.

TABLE XI.

Yield in lbs. per plant during first month of picking.

Pots.		Trays.	
Earliest of All.	Market King.	Earliest of All.	Market King.
1·50	1·24	1·03	0·74
Mean 1·37		0·88	

S.E. = 0·081.

The differences for the second month of picking and for green fruit picked at the end of the season were not significant, as may be seen from Table XII. There was also a highly significant

TABLE XII.

Crop yield in tons per acre from plants raised (i) *in pots and* (ii) *in trays* (*Wilmington,* 1943).

	Earliest of All.		Market King.	
	Raised in pots.	Raised in trays.	Raised in pots.	Raised in trays.
August picked ..	7·77	5·36	6·39	3·83
September picked	8·05	8·39	8·42	8·47
Total ripe fruit..	15·82	13·75	14·81	12·30
Green fruit.. ..	4·19	3·88	5·15	6·89
Total yield ..	20·01	17·63	19·96	19·19

difference between the yields of the two varieties in the first month of picking, which bears out the general result of the variety trials described earlier in this report.

The experiment was repeated in 1944 at Wilmington and at East Malling. The results obtained at East Malling, set out in Table XIII, confirm those of 1943. The plants planted from pots gave higher yields than those planted from trays.

TABLE XIII.

Crop yield in tons per acre of plants raised (i) *in pots and* (ii) *in trays* (*East Malling*, 1944).

	Harbinger.		Market King.	
	Raised in pots.	Raised in trays.	Raised in pots.	Raised in trays.
August picked ..	2·89	0·41	3·68	0·18
September picked ..	4·92	4·66	5·35	3·45
October picked ..	1·56	2·23	2·29	1·25
Total ripe fruit	9·37	7·30	11·32	4·88
Green fruit	8·35	6·65	6·95	4·67
Total yield ..	17·72	13·95	18·27	9·55

As in the Wilmington experiment in 1943 there was a highly significant difference in crop yield during the first month of picking. This is readily seen from Table XIV. The

TABLE XIV.

Yield in lbs. per plant during the first month of picking.

	Pots.		Trays.	
	Harbinger.	Market King.	Harbinger.	Market King.
	0·67	0·62	0·10	0·04
Mean	0·64		0·07	

S.E. = 0·43.

differences between crop yields for the subsequent months of picking and for the green fruit picked off at the end of the season were not significant. In the experiment at Wilmington in 1944, the yield of ripe fruit was very low and it would be unwise to take the results into account.

The results of the experiments described above definitely suggest that tomato plants planted from pots will give a higher and earlier yield than those of the same age planted from trays.

SUMMARY.

1. An account is given of trials and experiments carried out on the production of tomatoes in the open.

2. Four varieties, Earliest of All, Market King, Harbinger and Early Market, under the conditions of trial, showed themselves to be very suitable for growing in the open.

3. Earliest of All and Harbinger gave significantly earlier crops than the majority of the varieties included in the trials. X-Ray and Ailsa Craig were significantly later in producing mature fruit than most of the other varieties.

4. Experiments on the planting distance for tomatoes grown in the open are described. An increase in yield per acre was obtained but this was not proportionate to the increase in plant population except when the plants were grown in double rows.

5. Manurial experiments which indicate the value of dressings of stable or farmyard manure are described and discussed. The addition of farmyard manure gave a significant increase in yield of fruit picked ripe, and of fruit picked green at the end of the season. Evidence was obtained that added nitrogen is beneficial when dung is present, but that added potash is of little value.

6. The use of formaldehyde for partial soil sterilization of land to be used for outdoor tomato production did not produce any significant differences in the two years of the experiment.

7. A trial of plants raised in pots *versus* those raised in trays for planting in the open showed that the former produced a significantly earlier crop and a higher total yield of both ripe and green fruit than the latter.

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APPENDIX.

I. DATES OF CULTURAL OPERATIONS.

	Seed sown.	Seedlings potted into 60's.	Planted in open.	First picking.	Last picking.
1941 ..	26th March.	17th April.	27th May.	22nd Aug.	13th Oct.
1942 ..	7th April.	27th April.	19th May.	21st Aug.	13th Oct.
1943 ..	6th April.	27th April.	25th May.	27th July.	12th Oct.

II. MANURIAL TREATMENTS.

(*a*) *Variety, Planting Distance, Formaldehyde and Pots* v. *Trays Experiments.*

All plots received a dressing of farmyard or stable manure at the rate of 25 tons per acre.

Fertilizer dressings were as follows :

1941 and 1942. 4 oz. hoof and horn meal per sq. yd.
4 oz. bone meal per sq. yd.
4 oz. sulphate of potash per sq. yd.

1943. 3 oz. hoof and horn meal per sq. yd.
2 oz. superphosphate per sq. yd.
1 oz. muriate of potash per sq. yd.

(*b*) *Manurial Experiment.*

1942. Plots receiving added nitrogen were given a dressing of 2 oz. hoof and horn meal per sq. yd., and those receiving potash were given a dressing of 2 oz. sulphate of potash per sq. yd.

1943. Nitrogen was added as in 1942, and plots receiving potash were given a dressing of 2 oz. muriate of potash per sq. yd.

In both years all plots received a dressing of superphosphate at the rate of 4 cwt. per acre.

III. General treatment.

The plants in all the trials and experiments were trained on single stems and were stopped by August 11th in each year. Dusting with Bordeaux powder was carried out for Blight control as frequently as was deemed necessary. Any fruit which was still green when the final picking was done was taken into glasshouses for ripening.

(*Received* 7/9/44.)

EXPERIMENTS WITH GROWTH SUBSTANCE SPRAYS FOR REDUCTION OF PRE-HARVEST DROP OF FRUIT

By M. C. VYVYAN
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INTRODUCTION.

It is barely six years since Gardner, Marth and Batjer (1939) published their classic paper on the reduction of fruit drop by the use of hormone sprays, and followed this by fuller reports (Gardner, *et al.*, 1940, Gardner, 1940). Their results were obviously of immediate practical importance, and stimulated much similar work in the U.S.A. and elsewhere. Trials were begun at East Malling in 1940 to determine whether these sprays were likely to be of value with English varieties under the local conditions. This paper is a full report on these trials ; brief progress reports on most of them have already appeared elsewhere (Vyvyan, 1941, 1942, 1943, 1944).

A full review of the work of Gardner, Marth and Batjer, and of the other investigators on these sprays is at the Press, so only a brief outline of their main results will be given here. Gardner and his collaborators were led to their investigation by consideration of the effect of certain growth substances in postponing leaf-fall and the shedding of petioles whose lamina had been removed. As fruit drop in the apple, like leaf-fall, is due to an abscission process, they examined the possibility of its being affected in the same way. They tried several synthetic growth substances and found certain of them very effective ; these were α-naphthalene acetamide, α-naphthaleneacetic acid and the salts of the acid. Indole derivatives had far less effect. They suggested that other more potent substances might be found, but, up to the present, few of those tested have shown much promise. Most workers have used the acetamide, or the acid, or one of its salts ; some have compared their relative potencies, but no consistent differences have been found. All seem equally effective in preventing fruit drop and equally harmless to mature leaves and stems; but for very early applications the acetamide is to be preferred, as the acid sometimes causes distortion and twisting in young stems and leaves.

Gardner and his collaborators showed that the seat of the action of the growth substance was the fruit stalk ; wetting the calyx end of the fruit alone had little effect and wetting the leaves alone seemed to have none. Most workers have emphasized the necessity for very thorough spraying, to ensure wetting these stalks ; the usual recommendation in the U.S.A. has been for one and a quarter to one and a half gallons of spray for every bushel of fruit on the tree. In England, where the slightly larger " Imperial " gallon is in use, this would work out at about one gallon, or slightly more, per bushel. Some workers have applied the " growth substances " in the form of dusts, e.g. Hoffman, *et al.*, 1942, and good results have occasionally been obtained.

Workers on the apple have found great varietal differences in the time and intensity of the drop, and in its response to treatment with growth substances. This seems partly due to morphological characters ; for example, varieties with long-stalked, pendant fruit usually respond particularly well, probably because the stalks are easily wetted. Season of ripening is sometimes important ; early varieties usually respond better than late season. A few varieties of pear have been tested and some have responded even better than apples, and sometimes to lower concentrations. A little work has been reported on apricots and peaches, but not much success was obtained.

Great seasonal differences have been found both in the intensity of pre-harvest drop, and in its response to growth substance sprays. High temperatures seem to increase both the intensity of the drop and the success of the control measures. Soil conditions are also important ; high soil fertility sometimes seems to increase the intensity of the drop and to

make control measures more necessary. Considerable climatic differences have also been noted.

A characteristic of these sprays is the very low concentration required. One part per million (0·0001 per cent.) has sometimes had an effect; five parts per million (0·0005 per cent.) has been recommended (Batjer, 1943) as the most suitable strength for use on early varieties in hot weather. Ten parts per million, commonly called the "standard" strength, is the one recommended by the makers of most commercial "anti-drop" sprays. Higher concentrations seem necessary for certain difficult varieties.

The effect of the sprays becomes apparent after a few days, reaches a maximum in ten days or a fortnight, remains fairly constant for a period, then rapidly dwindles. The length of the effective period is said to depend largely on the variety and on weather conditions and very little on spray concentration. In McIntosh, for example, it is only ten days to a fortnight, while in some varieties it may be more than four weeks. The period is usually longer in cool weather than in hot. It will be shown below, however, that the methods usually employed to estimate intensity of drop, and magnitude of response to treatment, are liable to give somewhat misleading results.

Time of application is very important; the aim is to make the period of greatest effect coincide with that of greatest natural drop. The usual recommendations are, to spray either when the first few "commercial" fruits fall, or, alternatively, some ten days or so before a heavy drop is expected. The evidence on the value of "repeat" sprays is conflicting, although in general, it suggests that two or three applications, at intervals of a few days, give no more protection than one applied at the right moment, but give a better chance of striking that moment.

Considerable work has been reported on the effect of adding other substances to the hormone sprays; spreaders and summer oil have sometimes increased their effect. It would obviously reduce expense if the growth substance could be added to a routine insecticide or fungicide spray, but unfortunately these are usually applied too early; the substance might lose its effectiveness before the fruit began to drop. There is some evidence, too, that certain routine sprays, especially those including lime, may sometimes reduce the efficiency of the growth substance.

In general, it can be said that these "growth substance" sprays, applied to a suitable variety at the appropriate time, in a season of heavy drop, already provide a valuable protection against loss of crop in certain localities. They seem to be in full commercial use in some areas; for example, some 75,000 to 80,000 acres of apples were sprayed with them in the U.S.A. in 1942 (Batjer, 1943). More work, however, is required on them, especially in countries where they have not been tried on a large scale.

Material and Methods.

Varieties.—The purpose of the experiments was to determine whether growth substance sprays were likely to be of practical value with English varieties grown under East Malling conditions. Attention was therefore concentrated on those varieties in which loss by pre-harvest drop tends to be considerable, or picking is usually carried out early to avoid such a drop. Choice of variety was, however, partly dictated by availability of material.

Five varieties of apple, and one of pear, were used. These were: Beauty of Bath (1940 and 1945), Cox's Orange Pippin (1940, 1943 and 1945), Worcester Pearmain (1940, 1943 and 1945), Miller's Seedling (1941), Bramley's Seedling (1942, 1943 and 1945), and the pear, Conference (1942 and 1943). The dates refer to the seasons in which they were tried.

Lay-out.—The experiments were arranged in blocks. As far as possible the trees in each block were close neighbours, but in some cases, where the variety was interplanted with others, they were some distance apart. One tree, selected at random in each block, received each treatment. An exception to this rule was the trial with Worcester in 1943; this was planned

as a demonstration rather than as a trial, and was therefore made as simple as possible. Here there were four rows, each of eight trees ; the two inner rows were sprayed and the two outer left unsprayed as controls. The outer rows, however, were under conditions similar to the inner, as they formed part of a large plantation.

In the 1945 experiments with Bramley's, plots of more than one tree were used as units.

Treatments.—The main substance used was the one that had proved most successful elsewhere—α-naphthaleneacetic acid. In one experiment, Bramley's 1942, this was compared with α-naphthalene acetamide. The pure crystalline chemicals were used in most cases ; preparations containing known quantities of the chemicals were used in some of the later experiments. The chemical was usually applied alone, without spreaders, but in the experiments with Cox, it was combined with 1 per cent. summer oil, to see whether it would control oil-induced drop. In one experiment it was applied early, combined with the last routine lead arsenate spray. The concentrations ranged from $2\frac{1}{4}$ to 10 parts per million. The treatments will be described more fully in the experimental section below.

Data collected.—All dropped fruits already under the trees were collected, counted, and removed, at the start of each experiment, either just before, at the time of, or just after the sprays were applied. This was done primarily to prevent them from getting mixed up with the fruits dropped during the experimental period. Incidentally, these counts gave a measure of the dropping tendency of individual trees before the sprays were applied. Fruits dropped subsequently were collected at intervals, usually of two or three days, until the crop was picked. Those from each tree were counted. Except in certain of the earlier experiments, the sound fruits were separated from damaged or diseased ones, and weighed. This was done to secure a more reliable measure of the weight ; the weights, however, proved of no particular interest and are not given in this paper. The relative numbers of sound and unsound fruit, dropped during the successive periods, were incidentally obtained, and in certain instances proved of interest. As it was essential to complete each collection on a single day, it was not found practicable to attempt to examine the individual rejected fruits, to determine the cause of their " unsoundness ".

The fruits picked from each tree were also counted and weighed, or the numbers estimated by counting sample boxes, and the initial number of fruits, present on each tree at the time of treatment, was estimated by summing the numbers of picked and dropped fruits.

Statistical Analysis.—The significance of all differences between treatments was examined by the usual method of analysis of variance. The variance due to " treatment " was split into as many portions as there were degrees of freedom,—or valid comparisons (Wadleigh and Tharp, 1940). That due to " error " was similarly split into its component parts, one portion for each comparison. The homogeneity was then tested by calculating the quotient between the geometric and arithmetic means, and comparing this with the appropriate " L " value. When homogeneous, the " mean square error " was used, otherwise each comparison was tested by its appropriate error.

Interpretation of Results.

The most important information required is the difference in relative size of the crops on control and treated trees on successive dates after spraying ; in particular on the date when the fruit would normally have been picked, or on some subsequent date when picking would have been more convenient, or the fruit in better condition to pick. This information can be derived from the summed dropped fruits from control and treated trees.

It is also desirable to know if the spray was applied on approximately the right date. Time of application is very important, for the effect takes some days to develop, increases to a maximum, then ultimately fades away. If the spray is applied too early, the effect may wear off before serious drop develops ; if applied too late, serious loss may occur before the spray becomes effective. The optimum time for application can be proved only by special

experiments, where several different dates are tried and compared, but some estimate can be attempted, even where only one date of application has been tried, by determining the relative rates of dropping for each period before picking and the relative effect of the treatments for each period after spraying. The maximum reduction in total drop may be expected where the periods of greatest drop coincide with those of greatest effect. This assumes that the percentage reduction in drop is independent of the actual magnitude of the drop, i.e. it assumes that where a 5 per cent. drop has been reduced to 1 per cent., a 20 per cent. drop would have been reduced to 4 per cent. There is no *a priori* reason for this assumption, but examination of the data suggests that, within reasonable limits, it does in fact hold good. With very early and very late sprays, however, the assumption is not legitimate.

It is thus necessary to obtain estimates of, (*a*) the summed dropped fruits up to the successive dates, (*b*) the relative rate of dropping and (*c*) the relative effect of the spray, during the successive periods between treatment and the harvesting of the fruit.

Presentation of Results.

The results of the 1940 experiment with Beauty of Bath are shown very fully, in Table I, as an example. To save space, only the more important results of the other experiments are given.

Accumulated percentage dropped fruits.—These are shown in the upper part of Table I, they represent the summed dropped fruits up to the successive dates of collection. The numbers

TABLE I.

Beauty of Bath, 1940.

Control, sprayed with tap water (*A*). *Treated, sprayed with α-naphthalenacetic acid at* 5 (*B*) *or* $2\frac{1}{2}$ (*C*) *p.p.m. Sprays applied July 24th ; fruit picked August 7th.*

Date		July 25.	July 27.	July 29.	July 31.	Aug. 2.	Aug. 5.	Aug. 7.
Days since Spraying		1	3	5	7	9	12	14
Interval		1	2	2	2	2	3	2
Accumulated Percentage Drops	p.p.m.							
	Nil. A	3·9	25·7	44·5	62·6	78·6	86·1	88·9
	5 B	7·1	36·9	47·8	55·8	59·9	63·6	65·4
	$2\frac{1}{2}$ C	5·4	28·8	39·3	49·8	58·4	65·9	67·9
		+	+	—	—	—	—	—
	Mean diff.	2·3	7·1	0·9	9·8*	19·4*	21·3†	22·2†
	% diff.	**59**	**28**	**2**	**16**	**25**	**25**	**25**
Percentage Drops per Day	Nil. A	3·9	10·9	9·4	9·2	8·0	2·5	1·4
	5 B	7·1	14·9	5·5	4·0	2·2	1·2	0·9
	$2\frac{1}{2}$ C	5·4	11·7	5·2	5·2	4·3	2·5	1·0
		+	+	—	—	—	—	—
	Mean diff.	2·3	2·4	4·0†	4·6†	4·8†	0·6	0·5
	% diff.	**59**	**22**	**43**	**50**	**60**	**25**	**36**
Rate of Dropping	Nil. A	4·1	13·6	15·4	20·7	28·1	17·5	15·5
	5 B	7·6	21·8	11·9	10·7	5·1	3·3	2·8
	$2\frac{1}{2}$ C	5·5	15·6	9·2	10·8	11·0	8·0	5·2
		+	+	—	—	—	—	—
	Mean diff.	2·5*	5·1	4·8*	10·0†	20·0†	11·8†	11·5†
	% diff.	**41**	**38**	**31**	**48**	**71**	**67**	**74**

Note.—Mean diff. $=\frac{1}{2}(B+C)-A$: % diff. $=100\ (\frac{1}{2}(B+C)-A)/A$.

* Significant ($P=0\cdot05$). † Very Significant ($P=0\cdot01$).

of dropped fruits are expressed as percentages of the numbers present on the trees on the date when the spray was applied, for the differences in actual number of fruits dropped might be a mere reflection of differences in initial number—a tree bearing 200 fruits may be expected, under similar conditions, to drop twice as many as a tree bearing only 100.

In a preliminary report (Vyvyan, 1941), residual percentages of fruit on the trees were shown rather than the accumulated percentages of fruits on the ground; this method has the advantage of showing, at once, the relative sizes of the crops. The use of accumulated percentage fruits dropped, however, has become so general in the literature, that it has been adopted here. Obviously either value can readily be derived from the other, as they must together add up to 100.

Fruits dropped per day.—In order to know at what period control of drop is most required, it is necessary to determine the times when dropping is most severe. At first sight the obvious method might seem to be to determine the percentage dropped fruits for each successive period, by deducting the value for accumulated percentage drop for the date at the end of the period from that for the date at its beginning. Differences in the time interval might be adjusted by dividing the resulting value by the number of days. The values so found are shown in the middle portion of Table I. In the same way it might appear that the relative effect of the spray during successive periods could be determined by comparing the values for "drops per day" for sprayed and unsprayed trees. For example (Table I), it might appear that the 2½ p.p.m. spray was without effect during the period August 2nd-5th, because the "drop per day" had the same value—2·5 per cent.—as for the unsprayed trees. Closer consideration, however, suggests that this conclusion would be misleading, for it takes no account of the difference in residual percentages of fruit on the trees. On August 2nd these residual numbers were 21·4 and 41·6 respectively on the unsprayed and the sprayed trees. Now the value 41·6 per cent. may be regarded as made up of two parts: (*a*) some 21·4 per cent. corresponding to the fruit on the unsprayed tree and representing the value that might have been expected had the trees not been sprayed, and (*b*) the remainder, 20·2 per cent. representing the additional fruit kept on the tree through past effect of the spray. If the spray was no longer having effect, it follows that part (*a*) was dropping at the same rate as from the unsprayed trees, i.e. the drop would have been 2·5 per cent.; but as this was the total drop, part (*b*) cannot have been dropping at all. If, on the other hand, some of the drops were from the fruit kept on in the past by the spray, then those that would have stayed on in any event must have been dropping at a slower rate than 2·5 per cent. per day. Either way, it is evident that the spray was still having some effect. Clearly, therefore, residual percentages must be taken into account.

Rate of Drop.—It has been shown above, that the drop during each period should be expressed in terms of the residual number of fruits on the trees. The simplest method might appear to be to express those for each period as a percentage of the residual number at the start of that period. Fisher (1921), dealing with a different problem, has pointed out the inaccuracies that may arise when percentages are calculated in this manner, especially when dealing with large differences between initial and final values, and when the periods are of unequal length. The top line of values in Table I can be used as an example of the troubles that may arise. The total drop during the fortnight was 88·9 per cent., that is about 44·5 per cent. per week. Of this, 62·6 per cent. fell in the first week, and 26·3 per cent. in the second. The residual number at the end of the first week was thus 37·4 per cent.; if the drop during the second week is expressed as a percentage of this number, it works out at about 70 per cent., so the mean drop over the whole fortnight becomes some 67 per cent., instead of 44·5 per cent. If the fortnight had been subdivided into even shorter periods, the mean value per week would have become higher still. Fisher has shown that these inconsistencies can be greatly reduced if the arithmetic mean between initial and final values, instead of the initial value, is taken as the denominator; he has shown, however, that the more satisfactory method is to use

the differences between their logarithms as the index of "rate". The "rates of dropping" given in the lower part of Table I were calculated in this manner, the equation used being:

$$Q=100(\log_e X_1-\log_e X_2)/(t_2-t_1),$$

where X_1 and X_2 are the numbers of fruits on the tree at times t_1 and t_2, (t_2-t_1) is the time interval in days, $_e$ is the base of natural logarithms, and Q is the required value of the "rate". This method has already been used in a progress report (Vyvyan, 1941), but in it logarithms to the base 10 were used.

This method of expressing the rates has certain further advantages; the value for each period is determined completely by the numbers of fruits present at the start and the end of the period, and is completely independent of the numbers present at the time of spraying, or picking. The values for different varieties, or for the same variety in different seasons, are all reduced to a comparable basis.

Effect of Treatment.—The values for percentage effect of the sprays, given in the bottom line of Table I, and plotted for various experiments in Figs. 1—5, were calculated from the equation:

$$q=100(Q_c-Q_s)/Q_c,$$

where Q_s and Q_c are the logarithmic rates for sprayed and unsprayed respectively, and q is the required index of effect. It is realized that this index is only an approximation of the percentage effect, since both numerator and denominator are themselves estimates, each with a standard error. It is also subject to other disabilities; for example, if a long period is divided into parts, the value found for the whole period, taken as a single unit, will not necessarily be the same as the mean of those found for its several parts. It seems, however, to be the best index available at the moment, and it does seem to give consistent values.

A conversion table for the transformation of values of summed percentage dropped fruits into values of Q is given in the Appendix.

Harmlessness of Sprays Used.

Before recommending the use of these growth substance sprays on fruit for human consumption, it was necessary to be sure that they would cause no harm. Gardner, 1940 had already provided evidence that the danger of toxic effects was very remote, but further tests seemed desirable. As already mentioned in a previous report (Vyvyan, 1942), Dr. Haddow, of the Chester Beattie Research Institute, undertook this investigation and reported that "No carcinogenic or other harmful effect has been obtained in experiments with α-naphthalene-acetic acid carried out for more than a year". In view of this report and the minute quantities of the substance involved, the sprays may be considered as reasonably safe to use.

EXPERIMENTAL SECTION.

Beauty of Bath.

Beauty of Bath is an early dessert variety of apple which is usually marketed as soon as picked. It is of high quality and good colour, if retained sufficiently long on the trees. Unfortunately the fruits tend to ripen unevenly, and are liable to drop heavily as they ripen; it is therefore difficult to harvest all the fruits in prime condition at a single picking. If harvested when the first 30 or 50 per cent. are ready, the remainder tends to be unripe. If picking is deferred until the last 30 per cent. are ripe, a considerable portion of the crop may be on the ground. It is usual to gather the fruits at two or more pickings, or else to allow them to drop naturally on to straw. Control of drop in this variety is therefore very desirable, as it would permit all the fruits to be gathered in prime condition, and possibly at a single picking. The fruits, however, tend to be short-stalked and carried in clusters—characteristics not usually associated with good response to growth substance sprays.

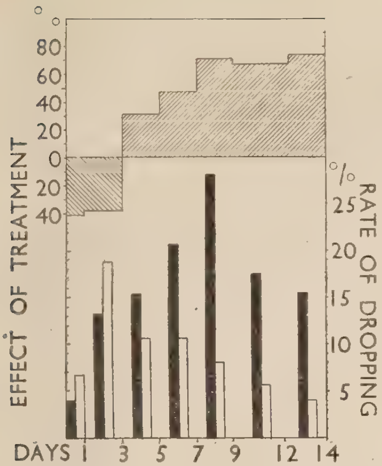

FIG. 1 BEAUTY OF BATH 1940

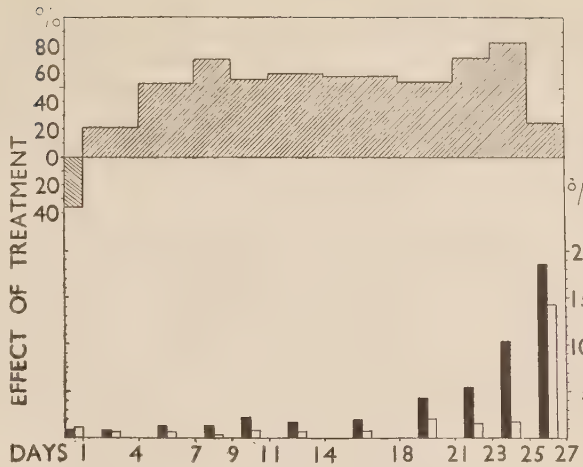

FIG. 2 MILLER'S SEEDLING 1941

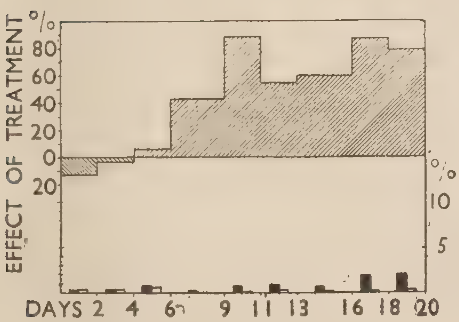

FIG. 3 WORCESTER 1940

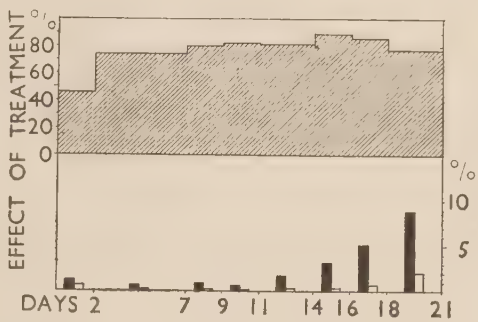

FIG. 4 WORCESTER 1943

EXPLANATION

EFFECT OF TREATMENT (q)

($q = 100 (Qc - Qs) / Qc$)

Percentage Reduction in Rate } = q
Percentage Increase in Rate }

RATE OF DROPPING (Q)

WITHOUT Growth Substance (Qc)

WITH Growth Substance (Qs)

$Q = 100 (\log_e X_1 - \log_e X_2) / (t_2 - t_1)$

Where X_1 and X_2 are the numbers of fruit on tree at times t_1 and t_2, $(t_2 - t_1)$ is the time interval in days and Q is the rate

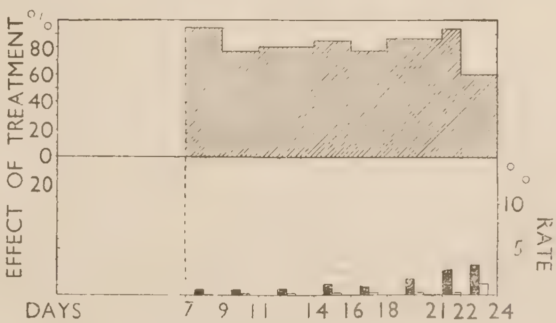

FIG. 5 CONFERENCE PEAR 1942

1940 *Experiment*.—In 1940 a row of 21 9-year-old trees on M. IX was available for a trial. The row was sub-divided into seven sections of three trees, which were sprayed with (A) tap water, (B) 5 p.p.m. and (C) $2\frac{1}{2}$ p.p.m., respectively, of α-naphthaleneacetic acid. This was the first test of these sprays at East Malling and unfortunately they could not be applied until July 24th—the date when the fruit would normally have been picked. To allow time for the sprays to take effect, picking was postponed for a fortnight, until August 7th. By that date the fruits showed some signs of being over-ripe and only 11 per cent. of those on the control trees had failed to drop.

Results.—The results of this experiment are presented very fully in Table I, as an example of the method of calculation. The values in the upper part of the Table are the accumulated drops, expressed as percentages of the initial numbers of fruit present on the date of spraying. The values in the centre are the drops per day during the successive periods, expressed on the same basis. The values in the lower part of the Table and in Fig. 1. are the rates of dropping, during the successive periods, calculated from the equation :

$$Q=(\log_e X_1-\log_e X_2)/(t_2-t_1),$$

where X_1 and X_2 are the numbers of fruit on the tree at the beginning and end of the period, (t_2-t_1) is the length of the period in days, and Q is the required rate of drop.

In each case the difference between the mean value for sprayed trees and that for the controls is given and is further expressed as a percentage of the corresponding value for the controls. Examination of the values for the accumulated percentage drops, shows that the control trees lost 4 per cent. of their fruit during the first twenty-four hours, some 26 per cent. in the first three days, over 60 per cent. in the first week, and nearly 90 per cent. in a fortnight. The first effect of the sprays was to increase the drop, but by the end of a week they had caused a significant reduction, and by the end of a fortnight this was considerable and highly significant. The final value for the 5 p.p.m. spray was slightly, but not significantly, lower than that for the $2\frac{1}{2}$ p.p.m. Even with the reduction achieved, the drop was clearly calamitous, and the postponement of picking unjustified. Somewhat similar results have been reported for late sprays on McIntosh (Southwick *et al.*, 1941), and Baldwin (Murphy, 1941). Examination of the values for the rate of dropping shows that the sprays had a considerable effect during the second week, the reduction was very significant, amounted to some 70 per cent., and showed no signs of diminishing. If the sprays had been put on earlier, and this 70 per cent. reduction in drop had been established and maintained during the first as well as the second week, the estimated accumulated drop from the sprayed trees would have been about 8 or 9 per cent. by the third day, 25 per cent. by the end of the first week, and about 47 per cent. by the end of the second. Results at Long Ashton in 1944 (Swarbrick, 1945), with a spray at 20 parts per million, bear out this tentative suggestion ; a drop of 30 per cent. was reduced to 4 per cent.

1945 *Experiments*.—No suitable trees bearing a sufficient crop became available at East Malling until 1945, but two trials completed at the time of going to Press have confirmed the conclusion that this variety, Beauty of Bath, is likely to respond well to treatment and to be worth spraying on a commercial scale. The results were as follows :

Experiment 1.—Fifty-six 14-year-old trees on M. IX were used ; they formed part of the same plantation as those used in 1940. The trees were arranged in plots of four ; two, selected at random in each plot, were sprayed, the other two left unsprayed as a control. The spray was a preparation of α-naphthaleneacetic acid and was applied at a concentration of 10 parts per million on July 10th, 1945 ; it contained a spreader. Considerable drop occurred from the unsprayed trees during the first week and most of the remaining fruit was shaken off by a gale on the 15th. Little drop occurred from the sprayed trees. The surviving fruits were picked on July 16th, and the percentage drops were found to be 91·3 per cent. from the unsprayed trees and only 23·2 per cent. from the sprayed, a reduction of 68·1 per cent. in the

drop. As shown in Table XI, this represented a gain of some 39 lb. of fruit per tree and some 290 bushels per acre. The fruit from the sprayed trees seemed slightly softer than that from the unsprayed.

Experiment 2.—Thirty-two 30-year-old trees, arranged in four rows of eight, were used. Three rows were sprayed and the remaining row left unsprayed as a control. The spray was a preparation of α-naphthaleneacetic acid, but from a different source than that used in Experiment 1; it was applied, without a spreader, on July 7th at a concentration of 10 parts per million. The fruits were less mature on that date than those on the trees used in Experiment 1, and they were not picked until July 23rd. At the time of picking, the total drop and crop from each tree was determined to the nearest quarter bushel (approximately 10 lb.) and the percentage loss by dropping estimated. On this basis, the percentage drop from the unsprayed trees was 69 per cent., that from the sprayed trees only 9 per cent.—a reduction of 60 per cent. As shown in Table XI, this represented a gain of about 102 lb. per tree, or 295 bushels per acre. There seemed little difference in hardness between fruit from sprayed and unsprayed trees.

COX'S ORANGE PIPPIN.

1940, *α-naphthaleneacetic acid with, and after, petroleum oil.*—In some districts, including East Malling, summer oil sprays for the control of red spider cannot safely be used, as they often cause severe fruit drop. As oil is known to increase the efficiency of a growth substance spray, there seemed some prospect that a growth substance might reduce oil-induced drop. To test this an experiment was carried out in 1940 with twenty 11-year-old Cox's Orange Pippin trees.

Five trees (A) were sprayed with tap water alone—as a control, five (B) with a petroleum oil spray, five (C) with a mixture of oil spray and growth substance, and five (D) with oil followed, a fortnight later, with a growth substance spray. This last treatment was included because oil-induced drop may not occur until four weeks after spraying and the effect of the growth substance, applied at the same time as the oil, might not last till then.

The oil was used at 1 per cent., the growth substance (α-naphthaleneacetic acid) at 5 p.p.m. (·0005 per cent.). The sprays were applied on July 24th, and the dropped fruits were collected, at the usual intervals, until the remaining fruits were picked nine weeks later, on September 25th. Thus the sprays were put on much earlier than usual, because it was the control of oil-induced drop, rather than of pre-harvest drop, that was being investigated.

In the statistical analysis, the three degrees of freedom between the four treatments were allocated to the differences between control and oil (A—B), growth substance with and after oil (C—D), and growth substance and none (A+B—C—D).

Results.—The accumulated percentage dropped fruits up to the end of the third, sixth and ninth week, the fruits dropped during picking, and the final total values, are shown in Table II. There were no significant differences between the values for the control trees and those receiving oil alone, or those receiving growth substance mixed with oil and those receiving it after oil. Thus oil-induced drop did not occur in these trees, so the effect of growth substance on its control was not determined.

There was, however, a very significant difference in drop between trees receiving growth substance and those receiving none. This difference was still very significant when the fruits were picked, nine weeks after spraying. There was thus no tendency for fruit, kept on in early days by the spray, to fall faster at some later date—as sometimes happens, e.g. in McIntosh.

The estimated net gain in pounds per tree and bushels per acre is shown in Table XI. This worked out at some 2½ lb. per tree or some 28 bushels per acre. These values, of course, are very approximate, as the values for the significant differences show; an apparent gain of as much as 19 bushels might be expected to arise by chance as often as once in twenty occasions.

The rate of dropping, and the effect of the sprays on that rate, are not given here, but

the difference in rate was significant during the first three weeks and very significant during the fourth ; thenceforward the fruit on the sprayed trees dropped at a consistently, but not significantly, lower rate than that on those receiving no growth substance.

1943. *α-naphthaleneacetic acid applied with petroleum oil.* A further experiment with oil and growth substance was carried out on Cox in 1943 ; the treatments were the same as in 1940, except that " D " (G.S. after oil) was left out and the controls "A" were unsprayed instead of receiving tap water. The trees were top-worked, very variable in size, and rather far apart in a mixed plantation of apples. There were eleven trees under each treatment. The sprays were applied on July 12th and the fruits were picked on September 19th.

The accumulated percentage dropped fruits over the whole period were: A (Control) 21·5 per cent., B (oil alone) 22·4 per cent.and C (oil plus G.S.) 16·6 per cent., very nearly the same values as those found in the former experiment. Unfortunately, the trees proved very variable, and none of the differences, either in summed drops, drops per day or in rates of drop, was significant. Most of the fruits fell during the last nine days, or during picking ; very few fell during the first four weeks—the period when spray effect might be expected. A detailed table of full results is not given here, but the estimated crops per tree and per acre are shown in Table II. As oil-induced drop did not occur in the trees used in either season, 1940 or 1943, the effectiveness of hormone sprays in preventing such drop has still to be determined.

TABLE II.

Cox's Orange Pippin, 1940.

Summer petroleum oil at 1 per cent. G.S.=α-naphthaleneacetic acid at 5 p.p.m. Sprayed July 24th. Picked September 25th.

	Accumulated Percentage Drops.				
Weeks after treatment	3	6	9	During picking.	Total.
Tap water alone	5·1	13·3	21·1	3·7	24·8
Oil alone	5·9	14·4	21·9	4·1	26·0
Oil mixed with G.S.	3·7	8·4	14·7	4·3	19·0
Oil; G.S. 14 days later	4·0	6·9	13·9	4·3	18·2

Bracketed values not significantly different.

1945 *Experiment.*—Batjer and Marth (1945) have recently reported good results from a spray of 2-4-dichloro phenoxyacetic acid and have suggested that a spray containing both this chemical and the more usual naphthaleneacetic acid might be worth trying. An experiment on these lines was carried out on Cox in 1945. Fifty-six trees were used and four treatments were tried; these were : Control, each chemical alone, and the two chemicals mixed in the same spray. Each chemical was used at a strength of 10 p.p.m. Unfortunately all the trees, both control and sprayed, suffered from a severe attack of Brown Rot and there was practically no pre-harvest drop of sound fruit ; the results were therefore inconclusive.

WORCESTER PEARMAIN.

1940, *α-naphthaleneacetic acid at two concentrations, 5 and 2½ p.p.m.*—Twenty-four mature top-worked trees, consisting of two rows of pollinators in a mixed apple plantation, were sprayed on August 17th, about three weeks before normal picking time. Little drop had occurred. The treatments were : A, control (tap water), B, 5 parts per million, C, 2½ parts per million. The fruits were picked on September 6th, the normal picking date, and the results are shown in

Table III and Fig. 3. The rates of dropping were low, but the sprayed trees showed a significant reduction by the 13th day, and by the 20th this had become about 80 per cent. and was very significant. The effects of the two concentrations were not significantly different. At the time of picking the accumulated dropped fruits from control and sprayed trees amounted to 14·4 and 5·8 per cent. respectively. As there was no sign yet of a diminution in spray effect, it is probable that picking could have been postponed a further week without serious loss, though there might have been some danger of over-ripening.

TABLE III.

Worcester Pearmain, 1940.

G.S.=α-naphthaleneacetic acid. Sprayed August 17th. Picked on normal date, September 6th.

	Accumulated Percentage Drops.		
Days after spraying..	6	13	20
Water alone	2·7	6·0	14·4
G.S. at 5 p.p.m.	2·6	4·0	6·6
G.S. at 2½ p.p.m.	2·6	3·6	5·0

Estimated gain in crop.—The mean weight per apple at picking was unfortunately not determined, but if the value—0·1838 lb.—found for the same variety in 1943, is used, the gain works out at 4·5 lb. per tree. As the trees were planted at the rate of 302 per acre, this represents a gain of some 34 bushels per acre, as shown in Table XI. These results suggest that the spraying was worth while, even though the fruit on the control trees did not drop heavily and picking was done at the normal time.

1943, *α-naphthaleneacetic acid at 10 p.p.m.*—Four rows, each of eight mature trees, in the old pruning plot were used. As this trial was planned as a demonstration, rather than as an experiment, the lay-out was made as simple as possible. The two centre rows were sprayed on August 17th and the two outer left unsprayed as controls. The row, rather than the tree, was thus the unit, and statistical tests for significance are not strictly legitimate. The fruits were picked on September 7th—four days later than they would normally have been picked.

Results.—The accumulated percentage drops of sound fruit, up to the second, ninth, sixteenth and twenty-first day after spraying, are shown in Table IV, together with the percentage of unsound fruit per row. The final values are the totals of sound and unsound. It

TABLE IV.

Worcester Pearmain, 1943.

Two rows (A and D) unsprayed ; two rows (B and C) sprayed with 10 p.p.m. α-naphthaleneacetic acid, at 5 gallons per tree. Average crop about 5 bushels.
Trees sprayed August 17th. Picked September 7th.

		Accumulated Percentage Drops. (Sound fruit).				Bad fruit.	Total Percentage Drop.
Days after Spraying		2	9	16	21		
Unsprayed	A	1·0	2·3	8·6	31·7	17·8	49·5
	D	0·6	2·6	8·3	30·6	8·6	39·2
Sprayed	B	0·6	1·0	1·8	7·2	5·3	12·5
	C	0·5	0·7	1·5	8·6	4·8	13·4

is obvious that the fruit on the two rows of unsprayed trees (A and D) dropped much more heavily than that on the two rows of sprayed ; the differences are so great that their significance can hardly be in doubt, though the design of the demonstration did not allow statistical tests to be tried. When the percentages were worked out for the individual trees, it was found that the lowest drop for a control tree was greater than the highest drop from a sprayed tree.

The estimated gain, shown in Table XI, is very high, representing more than a bushel and a half per tree and some 180 bushels per acre. Even if the fruit had been picked on September 16th, the gain in crop would have been considerable. It is of interest to note that the final loss (7·2 and 8·6 per cent.) from the sprayed trees up to September 21st, is less than that from the controls (8·3 and 8·6 per cent.) up to the 16th. It must be emphasized, however, that the significance of these differences has not been proved, and, strictly speaking, they may have arisen by chance.

The rates of dropping, and the effect of the spray on the rates, are shown in Fig. 4. These indicate that the spray was very effective. The percentage reduction in the rate was 75 per cent. by the end of the first week, and never fell below that value until the end of the third week. This suggests that the spray was put on at about the right time : the full effect developed before the onset of heavy drop, and was maintained until the fruits were picked.

1945 *Experiment*.—The same trees as in 1943 were used and were grouped into eight blocks of four ; two trees in each block were left unsprayed, the other two were sprayed on August 13th with a preparation of α-naphthaleneacetic acid, containing no spreader, at a concentration of 10 parts per million. All fruits already on the ground at the time of spraying were collected and counted. The fruits from thirty of the trees were picked on August 30th-31st and the number from each tree was expressed as a percentage of the number present on the date of spraying.

In the unsprayed trees these values ranged from 26 to 51 per cent. with a mean value of 41 per cent., in the sprayed trees they ranged 68 to 87 per cent. with a mean of 77 per cent. Thus there was a difference of 36 per cent. between the mean values, and one of 16 per cent. between the highest value for the unsprayed and the lowest for the sprayed. Statistical analysis was therefore considered unnecessary. The gain from spraying worked out at about 92 lb. per tree or 254 bushels per acre. (Table XI.)

One sprayed and one unsprayed tree were left unpicked for a further fortnight ; when the fruits were picked on September 14th, thirteen half-bushel boxes were obtained from the sprayed tree but only seventeen fruits from the unsprayed.

Miller's Seedling.

1941, *α-naphthaleneacetic acid at two concentrations*, 5 *and* 10 *p.p.m.*—This variety often tends to drop its fruits heavily before they are ready for picking, it seemed therefore a suitable variety for a pre-harvest spray. Twenty-seven mature trees, arranged in nine blocks of three, were used ; one tree in each block received tap water (A) as a control, the others received α-naphthaleneacetic acid at concentrations of 5 (B), and 10 (C) parts per million respectively. The sprays were applied at a rate of about two gallons per tree on August 7th. The fruits on the other trees of this variety on this plot were picked on August 28th, but those on the experimental trees were left until September 3rd to provide evidence of the duration of spray effect. By this date dropping had become heavy. The results are shown in Table V and Fig. 2.

Accumulated percentage dropped fruits.—There was some indication of a reduction in drop by the end of the first week. By the ninth day it had become significant and by the eleventh very significant. The total drop from the controls up to the normal date for picking, August 28th, was about 32 per cent. ; that from the sprayed trees only about 16 per cent. The drop was thus halved. By September 1st the sprayed trees had lost only about 21 per cent. though the controls had lost more than this a whole week earlier.

TABLE V.

Miller's Seedling, 1941.

Control (without growth substance) *sprayed with tap water alone.*
Treated (with growth substance) *sprayed with α-naphthaleneacetic acid at* 10 *parts, or* 5 *parts per million.*
Spray applied on August 7th. Fruit picked on September 3rd. Normal picking date August 28th.

	Accumulated Percentage Drops.			
Days after Spraying	7	14	21	27
With Growth Substance 10 p.p.m. ..	5·6	9·3	15·7	36·6
5 p.p.m. ..	3·9	8·1	16·6	40·1
Without Growth Substance	7·0	17·3	32·1	66·1

Rate of Drop.—The reduction in rate (Fig. 2), established by the seventh day, showed no sign of falling off, in fact the percentage reduction, 83 per cent., for the period ending September 1st was the highest. This shows that the spray was not put on too early, even though picking was postponed till the twenty-seventh day. Possibly even better results might have been obtained if spraying had been done a few days, or even a week, earlier. The comparatively low value for the final period, September 1st to 3rd, was obviously due to the fruits dropped during picking. The estimated gain was 137 bushels per acre. (Table XI.)

BRAMLEY'S SEEDLING.

The picking period of this important variety is late in the season, and often rather prolonged. Considerable drop occasionally occurs, and control of this by sprays might be of value, especially for the trees picked last.

1942 *Experiment. Two substances, applied on two dates.*—Some mature trees, bearing a considerable, but variable, crop, were available for a trial in 1942. As many fruits were already on the ground in early September, some five or six weeks before the expected picking period, it was decided to apply an early spray as well as one at the usual time.

A compact group of forty-eight trees was selected, and divided into six blocks of eight. Two trees, selected at random in each block, were sprayed on September 14th, two on October 2nd, and two on both dates. One of each pair received α-naphthaleneacetic acid, the other α-naphthalene acetamide* ; each at a concentration of 6 p.p.m. The other two trees were left unsprayed as controls. Some five gallons of spray were used on each tree on the first occasion and about two on the second. The dropped fruits already under the control trees, and those sprayed on September 14th, were removed on September 15th ; they were counted to get some measure of the drop per tree before spraying. Subsequent dropped fruits were collected, counted and weighed at intervals of a few days until the fruits were picked on October 17th. The picked fruits from each tree were likewise counted and weighed. The summed numbers of dropped fruits subsequent to September 15th and picked fruits gave the numbers of fruits present on each tree on that date. The fruits under each tree, sprayed on October 2nd only, were unfortunately not collected until September 21st and thus included drops subsequent, as well as prior, to September 15th ; the exact number present on that date could not therefore be determined.

Results.—This delay in the collection of the initial dropped fruits somewhat complicates the analysis of the data. For, if subsequent drops are to be expressed as percentages of the numbers

* Kindly provided by Plant Protection Ltd.

present on the 15th, the trees under these treatments must be omitted. If all trees are to be included, the percentages must be based on the numbers present on the 21st, and by then some of the treatments had begun to show some effect. The percentages were calculated on both bases, and the respective values were found to be not very different. The values for the trees sprayed for the first time on October 2nd, however, are of no particular interest before that date, so the method adopted was as shown in Table VI.

TABLE VI.

Bramley's Seedling, 1942.

Treated trees sprayed *either once* (*early or late*) *or twice* (*early and late*) *with either α-naphthalene-acetic acid or α-naphthalene acetamide at* 6 *parts per million.*
Control trees unsprayed.
Early sprays applied September 14th, late sprays applied October 2nd. Fruit picked October 17th.

		Accumulated Percentage Drops.								
		As percentage number of fruit on September 15th.						As percentage fruit on trees on October 2nd.		
Days		7	11	18	25	32	33	7	14	15
Early only	Acid	2·5	3·1	4·0	6·0	13·3	16·1	2·1	9·7	12·7
	Amide	2·7	3·4	4·2	6·4	13·6	16·2	2·4	9·8	12·6
Early and Late	Acid	1·9	2·3	3·5	5·4	10·3	13·5	1·9	7·0	10·3
	Amide	4·8	5·7	8·0	9·9	21·6	24·5	2·1	14·9	18·1
Late only	Acid	—	—	—	—	—	—	3·8	11·2	14·9
	Amide	—	—	—	—	—	—	3·0	10·6	13·7
Mean Sprayed		3·0	3·6	4·9	6·9	14·7	17·6	2·6	10·5	13·7
Mean Unsprayed		4·5	6·2	8·8	12·9	26·5	30·4	4·5	19·6	23·9

The fruits dropped from unsprayed trees, those sprayed early and those sprayed early and late, have been expressed as percentages of the numbers of fruits present on the 15th. The values of these accumulated percentages are shown in the left hand columns of the Table. The right-hand columns give the accumulated drops from trees under all treatments, expressed as percentages of the numbers present on October 2nd—the date of the second spray. At the bottom of the Table, the mean values for sprayed trees are compared with those for the unsprayed.

Examination of this Table reveals certain points of interest. In the first place, the mean percentage drop from the sprayed trees was considerably less than that from the unsprayed, and, by the date of picking, the difference was very significant. Secondly, the acid and the amide seem to have had about the same effect when applied early, or applied late, but very different effects when applied both early and late. In the latter case the acid seemed to give more control and the amide less control than a single spray of either applied on either date. The differences in the values, however, were already apparent before the second spray was put on, and cannot be attributed to differential response to that spray. The data were therefore examined to see if any explanation of these discrepancies could be found, and any method of adjustment devised, so as to impart greater precision to the results.

Many investigators have found considerable variation in percentage drop apart from that due to treatment, and some, e.g. Davey and Hesse (1942), have succeeded in increasing the precision of their results by adjusting the values for drop after treatment by those for drop before the sprays were applied. It is also known that relative size of crop may be related to severity of drop ; trees with heavy crops often shed a larger proportion of their fruit than

trees with light crops, owing, apparently to competition between the fruit. Relative proportions of sound and unsound fruit was another possible factor, for fruit suffering from certain troubles, such as codling moth, tend to drop early. Estimates of initial number of fruits and of drops before treatment were available, and the drops after treatment had been sorted into sound and unsound in order that weights might be based on sound fruit only. The data were therefore inspected to see if any obvious relations existed between these variables. It was at once apparent that, although the trees for each treatment had been selected at random in each block, those with large and small initial numbers and with severe and light initial drops, were distributed very unevenly between the treatments, as may be seen in columns 1 and 2 of Table VIII. For example, the trees receiving two applications of the acetamide had an exceptionally low initial number of fruits and high initial drop; four of the seven trees bearing less than 500 fruits chanced to be included amongst the six trees under this treatment.

Correlation coefficients were therefore worked out between these variables and are shown in Table VII. The values of accumulated percentage drops after spraying were those for October 16th, since those for the 17th include " drops during picking " and therefore all the " bad " fruit.

TABLE VII.

1. *Estimated Initial Number of Fruit.*
2. *Drops before Sept. 15 as percentage of 1.*
3. *Drops after Sept. 15 as per cent. number on Sept. 15.*
4. *" Unsound " Drops as per cent. number on Sept. 15.*
5. *" Sound " Drops as per cent. number on Sept. 15.*

N.B. (4+5)=2.

1st Order Coefficients.		2nd Order Coefficients.				3rd Order Coefficients.	
M12 M13 M23	−·5837† −·4660* +·5529†	M12·3 M13·2 M23·1	−·4422* −·2118 +·3911				
		M12·4	−·3403	M12·5	−·5288*	M12·45	−·3649
M14 M15 M24 M25	−·5250† −·3592 +·7418† +·3260	M14·2 M15·2 M24·1 M25·1	−·1690 −·2200 +·6300† +·1536	M14·5 M15·4 M24·5 M25·4	−·4140* −·0609 +·7236 −·2308	M14·25 M15·24 M24·15 M25·14	−·0535 −·1524 +·6532† −·2680
M45	+·6056†	M45·1	+·4250†	M45·2	+·5737†	M45·12	+·5580†

* Significant (P=0·05). † Very significant (P=0·01).

These coefficients show several points of interest. The high negative values $r_{12}=-0\cdot5837$ and $r_{13}=-0\cdot4660$ suggest that trees with large initial crops tended to drop more heavily both before and after spraying—which is contrary to expectation. The high coefficient $r_{23}=+0\cdot5529$ between drops before and drops after spraying show that certain factors, varying in intensity from tree to tree, were apparently influencing the tendency to drop both before and after spraying. The partials $r_{13\cdot2}$ and $r_{23\cdot1}$, however, were not significant.

Partition of the dropped fruits after spraying into " good " and " bad " provides further points of interest. The highly significant positive values of the coefficients r_{45}, $r_{45\cdot1}$, $r_{45\cdot2}$ and $r_{45\cdot12}$

show that drop of good and bad fruit was closely related and that this was not an indirect result of both being related to "initial numbers" of fruit, or to drops before spraying. The very high and significant values of the coefficients r_{24}, $r_{24\cdot 1}$, $r_{24\cdot 5}$ and $r_{24\cdot 15}$, between the "drops before" and the drop of "bad" fruit after spraying, taken in conjunction with the comparatively low and non-significant values of the corresponding coefficients r_{25}, $r_{25\cdot 1}$, $r_{25\cdot 4}$ and $r_{25\cdot 14}$, seem to suggest that the majority of the fruits that fell before the spray was applied did so because they were bad. The coefficient r_{15}, between initial number of fruits and drops of good fruits "after", is not significant and its partials are even smaller. The high value of the coefficient $r._{14}$ between initial number and the drop of "bad" fruit after spraying and the low values for the partials $r_{14\cdot 2}$ and $r_{14\cdot 25}$ indicate that initial number is negatively correlated with the drop of bad fruit, but only in so far as has already been foreshadowed by its relation to drops before spraying.

Table VIII.

Bramley's Seedling, 1942.

Adjustment of percentage drops by covariance with initial crop and drops before spraying.

Bramley 1942 Six Trees per Treatment. Twelve Trees Unsprayed.	Estimated initial number of fruit.	Drops before treatment as per cent. initial number.	Summed Drops from September 15th to October 10th as percentage fruit on trees on September 15th.								
			Unadjusted Values.			After adjustment by covariance. with :					
						Initial number of fruit.			Drops before Treatment.		
			Bad.*	Good.*	Total.	Bad.	Good.	Total.	Bad.	Good.	Total.
Early Acid	1,244	21·2	5·5	8·0	13·3	6·5	8·9	15·4	5·8	8·0	13·8
Early Amide	1,015	20·6	5·7	7·9	13·6	5·7	7·9	13·6	6·2	8·3	14·5
Early and Late Acid	1,053	18·5	4·9	5·4	10·3	5·1	5·7	10·8	6·2	6·3	12·5
Early and Late Amide	680	27·4	10·5	11·0	21·5	9·2	9·6	18·8	8·6	9·6	18·2
Mean (Sprayed)	988	21·9	6·6	8·1	14·7	6·7	8·0	14·7	6·7	8·0	14·7
Unsprayed	972	22·4	9·9	16·6	26·5	9·8	16·6	26·4	9·8	16·5	26·3
Difference	—	—	3·3	8·5	11·8	3·1	8·6	11·7	3·1	8·5	11·6
Significant differences (P 0·05)	—	—	—	—	4·8	—	—	4·4	—	—	4·1
(P 0·01)	—	—	—	—	6·5	—	—	5·9	—	—	5·6

* Bad = "unsound" fruit. Good = "sound" marketable fruit.

In general it would seem that the size of the initial crop bears a close negative correlation to the proportion of fruit dropped, both before and after spraying, and that this is mainly due to its relation to the drop of "bad" fruit. The solution is probably bound up with codling moth injury. Hansberry and Richardson (1935), according to Snedecor (1938), have provided evidence that "the intensity of the injury by codling moth larvae is greater in apple trees bearing a small crop. Apparently . . . the chance of attack for any particular fruit is augmented if there are few fruits on the tree".

Adjustment for Initial Crop and Initial Drop.—The values for accumulated percentage drop up to October 16th, adjusted by covariance with Initial Number of fruit, and for drops before spraying, are shown in Table VIII, where they are compared with the unadjusted values. It will be noticed that the exceptionally high values, found for the trees sprayed twice with the

amide, have been considerably reduced, whichever adjustment is made. The precision of the experiment has been considerably increased by the adjustments, as is shown by the reduced values for differences required for significance. The actual value for the difference between the fruits dropped from sprayed and unsprayed trees is about double that required for a significance of the order of $P=0 \cdot 01$.

Calculations based on all 48 trees, including those receiving a single spray applied on October 2nd, gave similar results, but are not given here. The accumulated dropped fruits were expressed as percentages of the numbers of fruit present on September 21st.

1943, *α-naphthaleneacetic acid and Lead Arsenate applied in June*.—The heavy early drop, found in 1942, suggested that a growth substance spray, applied early enough to be combined with lead arsenate for codling moth control, might be effective. To test this, twenty-eight mature trees, arranged in seven blocks of four, were used in 1943. They were on the same plot as in 1942 but were different trees. They were sprayed on June 21st ; two (B and D) in each block received lead arsenate at 2 lb. per 100 gallons plus α-naphthaleneacetic acid at $7\frac{1}{2}$ parts per million, the other two (A and C) lead arsenate alone. Trees C and D received a second application of growth substance alone, at the same concentration, on September 9th. All dropped fruits already under the trees were collected on June 18th—three days before the first application—subsequent drops were collected on June 24th and at intervals of two or three days until the fruits were picked, except for the period July 26th to September 8th, during which weekly collections were made. The results are shown in Table IX. The left-hand

TABLE IX.

Bramley's Seedling, 1943.

First spray *of $7\frac{1}{2}$ p.p.m. α-naphthaleneacetic acid applied, mixed with lead arsenate, on June* 21*st.*
Second spray *of same concentration of same substance applied alone on September* 9*th.*
Unsprayed *trees were controls. Fruit picked on September* 30*th.*

	Effect of First Spray (applied June 21st).				Effect of Second Spray (applied September 9th).			
	Accumulated percentage (based on number fruit on tree on June 18th).				Accumulated percentage (based on number fruit on tree on September 10th).			
Days	9	23	79	101	8	15	20	21
Sprayed	16·2	19·1	38·8	51·0	4·4	6·7	9·8	14·1
Unsprayed	16·0	20·5	40·2	51·4	6·2	11·4	16·4	20·8

portion of this Table refers to the effect of the first spray, applied on June 21st. Here the values of the accumulated drops, expressed as percentages of the numbers present on June 18th, are given for the 9th, 23rd, 79th and 101st day after spraying ; the 79th day being the one before the second spray was applied. It is obvious that the spray was completely without effect. Some 16 per cent. of the fruit fell within the first 9 days—apparently the tail-end of the "June drop" must have been included in the experimental period. More than 50 per cent. had fallen by the time the fruits were picked on the 101st day. Dropping never completely ceased throughout the period ; the highest value was during the first week when the logarithmic rate was some 0·5 to 0·6 per cent. per day. During the last week of June it fell to about 0·16 per cent. and for the next six weeks was under 0·10 per cent. per day. During August and September the rate was about 0·3 per cent.

The effect of the second spray, applied on September 9th, is shown in the right-hand portion of the Table. As all the trees were behaving alike at that date, this spray application has been treated as if it were a separate experiment, and the percentage drops have been based on the number of fruits present on September 10th. Half the trees shown here as sprayed, and half those unsprayed, had received the early application in June. It is clear that this second spray had a considerable effect. The actual gain, 6·4 per cent. does not appear large, but it is more than twice the value required for a highly significant difference ($P=0 \cdot 01$) and suggests that the gain in crop would be likely to be of the order of 20 to 60 bushels per acre.

The initial crops at the time of spraying were much more uniform than in 1942, and inspection of the data failed to reveal any evidence of a correlation between their values and those for percentage drop.

1945 *Experiments.*—As control of drop in this important variety is very desirable, further trials were carried out in 1945. In one a spray was used at the standard strength of 10 parts per million, in case the poor results in previous seasons were due to the relatively low concentrations—6 p.p.m. and 7½ p.p.m.—then used. In the other the growth substance was applied in a dust, instead of in a spray; some growers would find dusting more practicable than spraying at this time of the season. In both trials the dropped fruits were collected and counted in the usual manner, but the number of picked fruits was estimated by counting the boxes from each tree and determining the number of fruits in random boxes. In each trial there was a drop of some 20 per cent. of the fruit during the experimental period but in neither was there evidence of an appreciable control of this drop. (*vide* Table XI.)

Experiment 1.—*Spray at* 10 *p.p.m.*—Forty-two mature trees in a mixed plantation were used. They consisted of a row of twelve trees, a row of nine, and seven groups of three. In several groups the branches overlapped making individual treatments and individual counts of drops impracticable; three tree units were therefore used. Two such units constituted a block; one was left unsprayed, the other was sprayed on September 7th with naphthaleneacetic acid, without a spreader, at 10 p.p.m. The percentages picked from the unsprayed units ranged from 78 to 85, with a mean value of 82, those from sprayed ranged from 81 to 87 with a mean value of 84. Thus the gain from spraying was at most only 2 per cent. and was unimportant even if significant.

Experiment 2.—*Growth substance applied as a dust.*—A large block of mature trees was available. Ten five-tree units were used; several guard trees were left between units to reduce the danger of drift, which is more serious with dusts than with sprays. Five units received dust containing no growth substance on the evening of September 7th, and the other five received dust containing naphthaleneacetic acid at 0·1 per cent. on the following morning. About half a pound of dust was used per tree and was clearly perceptible on the leaves and fruit. Many of the fruits showed traces of the dust at the time of picking. The percentage picked was 20 in both control and treated trees.

Conference Pear.

1942, *α-naphthaleneacetic acid at* 4 *parts per million.*—Fourteen 20-year old trees, arranged in seven pairs, were used. One tree, selected at random, in each pair, was sprayed on September 14th, with 4 p.p.m. α-naphthaleneacetic acid; the other was left unsprayed as a control. The two members of each pair were next one another in the same row. The first collection of fruits dropped under each tree was made on the 21st—seven days after spraying—and included those that had fallen before the 14th. Subsequent collections were made at intervals of two or three days until the fruits were picked on October 8th; the last included fruits that fell in the course of picking. The values for "Accumulated Drops" shown in Table X are expressed as percentages of the numbers present on the trees on the 21st, because the numbers present on the 14th are not known. The drop in the interval 14th to 21st was very small, for the total drop

up to the 21st, including fruits that fell before the 14th, was less than 6 per cent. and was not significantly different for sprayed and control trees. The very low value—1·7 per cent.—for the drop during the period September 21st to 25th, coupled with the low value for total fruits on the ground on the 21st, suggests that there was little tendency for pre-harvest drop in these trees in 1942, and little need for control by a spray, provided the fruits were picked on the normal date. If, however, picking had had to be postponed for a fortnight until October 8th, the spray would clearly have been worth while as it resulted in a saving of some 16 per cent. of the crop, which worked out at some 23 lb. per tree or about 90 bushels per acre. In fact the drop from sprayed trees up to October 8th was about the same as that from the unsprayed up to September 25th. Spraying thus permitted postponement, but this does not mean that the delay would be justified on other grounds, for the danger of over-maturity must be guarded against in pears even more than in apples. The marked response of this variety to the spray (see Fig. 5), when dropping did ultimately develop, suggests, however, that a similar response may be expected when dropping does set in—as it often does—before the normal picking date.

TABLE X.

Conference Pear, 1942.

Treated trees sprayed *with* 4 *p.p.m. α-naphthaleneacetic acid.*
Control trees unsprayed.
Spray applied September 14*th. Fruit picked October* 8*th. Normal picking date September* 25*th.*

	Accumulated percentage drops, based on number of fruit on trees on September 21st.				
Days since Spraying ..	11	18	24	Bad fruit.	Total.
Sprayed	0·2	0·8	2·0	2·7	4·7
Unsprayed ..	1·7	7·3	18·4	2·2	20·7

1943, *α-naphthaleneacetic acid and Hortomone A at* 5 *p.p.m.*—A further trial with Conference pear was carried out in 1943. Thirty trees, arranged in ten blocks of three, were used; one tree in each block was left unsprayed, one received α-naphthaleneacetic acid, and the third a commercial preparation known as Hortomone A. This preparation is sold primarily for the inducement of roots in cuttings, but it is said to contain the acid, amongst other ingredients; it was used because the pure chemical was in short supply and no specific anti-drop spray material seemed then to be on the market in England. The spray was put on at the concentration of 5 p.p.m., or its equivalent in the active ingredient. The sprays were applied on August 16th and the fruits were picked on September 10th—the date when they would normally have been picked. Less than 5 per cent. drop occurred during the interval under any treatment, so the results were inconclusive. Thus there was again no serious pre-harvest drop, and therefore no need for control up to the normal harvest date.

DISCUSSION.

The experiments described above were designed primarily to determine whether growth substance sprays were likely to be of use for English varieties of apples and pear, grown under East Malling conditions. The data were incidentally used to devise methods of analysis that might assist in the proper timing of the sprays.

The concentrations used were in many cases rather lower than those usually recommended, and it is noteworthy that the largest net gains were achieved with Beauty of Bath in 1945,

TABLE XI.

VARIETY. Season. Trees per acre.	DATES. Sprayed. Picked. *Normal date.*	SPRAY. Substance p.p.m.	
BEAUTY OF BATH . . . . 1940 . . . . 302	July 24th. September 7th. *July 24th.*	N.A.A.* 5 or 2½	Per cent. picked. lb. per tree. *Bushels per acre.*
BEAUTY OF BATH . . . . 1945 (1) 302	July 7th. July 16th. *July 16th.*	N.A.A. 10	Per cent. picked. lb. per tree. *Bushels per acre.*
BEAUTY OF BATH . . . . 1945 (2) 111	July 7th. July 23rd. *July 23rd.*	N.A.A. 10	Per cent. picked. lb. per tree. *Bushels per acre.*
COX'S O.P. . . . . 1940 . . . . 435	July 24th. September 25th. *September 25th.*	N.A.A. 5	Per cent. picked. lb. per tree. *Bushels per acre.*
COX'S O.P. . . . . 1943 . . . . 151	July 12th. September 19th. *September 17th-19th.*	N.A.A. 5	Per cent. picked. lb. per tree. *Bushels per acre.*
WORCESTER PEARMAIN . . 1940 . . . . 302	August 17th. September 6th. *September 6th.*	N.A.A. 5 or 2½	Per cent. picked. lb. per tree. *Bushels per acre.*
WORCESTER PEARMAIN . . 1943 . . . . 111	August 17th. September 7th. *September 3rd.*	N.A.A. 10	Per cent. picked. lb. per tree. *Bushels per acre.*
WORCESTER PEARMAIN . . 1945 . . . . 111	August 13th August 31st. *August 31st.*	N.A.A. 10	Per cent. picked. lb. per tree. *Bushels per acre.*
MILLER'S SEEDLING . . 1941 . . . . 150	August 7th. September 3rd. *August 28th.*	N.A.A. 10 or 5	Per cent. picked. lb. per tree. *Bushels per acre.*
BRAMLEY'S SEEDLING . . 1942 . . . . 75	September 14th. October 17th. *October 6th-17th.*	N.A.A. or N.A.* 6	Per cent. picked. lb. per tree. *Bushels per acre.*
BRAMLEY'S SEEDLING . . 1943 . . . . 193	September 9th. September 30th. *September 21st-24th.*	N.A.A. 7½	Per cent. picked. lb. per tree. *Bushels per acre.*
BRAMLEY'S SEEDLING . . 1945 (1) 150	September 7th. October 5th. *October 5th.*	N.A.A. 10	Per cent. picked. lb. per tree. *Bushels per acre.*
BRAMLEY'S SEEDLING . . 1945 (2) 75	September 7th-8th. October 8th. *October 8th.*	N.A.A. Dust.	Per cent. picked. lb. per tree. *Bushels per acre.*
CONFERENCE PEAR . . 1942 . . . . 193	September 14th. October 10th. *September 25th.*	N.A.A. 4	Per cent. picked. lb. per tree. *Bushels per acre.*

* N.A.A. = α-Naphthaleneacetic acid. N.A. = α-Naphthalene acetamide.

Results.					Remarks.
Sprayed.	Unsprayed.	Difference (Gain).	Significant difference. P=0·05	P=0·01	
33·3 5·2 **39**	11·1 1·7 **33**	22·2 3·5 **26**	13·1 2·1 **16**		First trial. Sprayed and picked much too late.
77 44 **330**	9 5 **37**	68 39 **293**	6 3 **24**	7 4 **31**	Heavy gale on July 14th-15th.
91 160 **450**	31 56 **155**	60 104 **295**			Older trees in more protected position.
81·4 30·5 **331**	74·5 27·9 **303**	6·9 2·6 **28**	4·6 1·7 **19**	6·5 2·5 **26**	Spray applied very early with 1% summer oil.
83·4 42·8 **161**	78·0 40·0 **151**	5·4 2·8 **10**			As above, but trees very variable. Results not significant.
94·2 (49·3) **373**	85·6 (44·8) **339**	8·6 (4·5) **34**	5·5 (2·9) **22**		Little drop, picking could have been delayed.
87·1 186·7 **518**	55·7 119·3 **331**	31·4 67·4 **187**			Arranged as a demonstration. Statistical analysis not possible.
77 194 **538**	41 102 **284**	36 92 **254**			On same trees as 1943 experiment.
61·6 80·1 **303**	33·9 441 **167**	27·7 36·0 **137**	11·9 15·5 **58**		Picking postponed five days. Colour improved.
82·4 231 **433**	69·6 194 **366**	12·8 37 **67**	5·2 15 **27**	7;0 20 **37**	Acid and amide behaved alike.
85·6 304·3 **570**	79·2 281·5 **528**	6·4 22·8 **42**	2·2 7·6 **14**	3·0 10·5 **20**	An earlier spray, applied with lead arsenate, had no effect.
84·4 360 **1348**	82·1 349 **1312**	2·3 11 **36**			
80·4 455 **853**	79·6 451 **844**	0·8 4 **9**			
95·3 135·7 **557**	79·4 113·1 **464**	15·9 22·6 **93**			Picking postponed. Little drop up to normal picking date.

Miller's Seedling in 1941 and Worcester Pearmain in 1943 and 1945, where the materials were used at the "standard" strength of 10 parts per million. But in every case, including that of Miller's Seedling, wherever two concentrations were compared in a single trial, they both had about the same effect ; in no instance did the higher concentration result in a significantly greater gain.

The results of the various experiments are shown best, perhaps, by the values presented in Table XI, where the net gains in residual crop are estimated. These have been expressed in three ways, percentage gain in crop, gain in pounds per tree, and gain in bushels per acre. This last value is a very rough approximation, and must be interpreted with great caution, for it is notoriously unsafe to place undue weight on estimates of crops per acre based on values derived from a relatively small number of trees. This estimate is included mainly to adjust the results for the large differences in the size of the trees, and in planting distances. Obviously a small gain in pounds per tree, found for dwarf trees planted at the rate of 435 per acre, may mean more than a much larger gain per tree, in vigorous trees planted 75 per acre.

With regard to the response of individual varieties, the best results have been obtained with Beauty of Bath, Miller's Seedling, Worcester Pearmain apples and with Conference pear.

In the initial experiment with Beauty of Bath in 1940, the spray unfortunately had to be applied late—on the date when the fruit would normally have been picked. Heavy drop occurred during the ensuing week, before the spray had time to take effect. There was, however, a considerable reduction in the rate of drop in the second week after spraying, in spite of the rather advanced stage in the maturity of the fruit. This suggested that a spray applied some ten days or a fortnight earlier might have given good control. Two experiments in 1945 have completely confirmed this conclusion, each resulted in a gain of some 290 bushels per acre. The fruits were retained on the sprayed trees in spite of a gale that shook down most of those from the unsprayed trees. On the strength of these results, it can be confidently recommended that this variety should be sprayed at a concentration of 10 p.p.m. about a fortnight before the normal picking date.

Excellent results were also obtained with Miller's Seedling in 1941, when sprays of 5 or 10 p.p.m. were applied some three weeks before the normal picking date. The spray permitted a delay of some five days in picking without the serious loss that occurred in the unsprayed trees, and there was some indication of an improvement in colour. Use of the spray for this variety can therefore be fully recommended.

Worcester Pearmain, also, has responded well to the spray. In the first experiment, carried out in 1940, there was a considerable percentage reduction in drop, but the net gain was not large, because the fruits were picked on the normal date and no heavy pre-harvest drop had developed. In the second experiment, carried out in 1943, the picking was postponed for four days without serious loss from the sprayed trees. The gain worked out at over 180 bushels per acre, but, as the trial was planned as a demonstration rather than as an experiment, the significance of this large gain could not be proved by statistical tests. In the third experiment, carried out on the same trees in 1945, the gain from spraying worked out at some 250 bushels per acre. Picking on this occasion was during the normal period but these trees were the last to be picked. The use of the spray with this variety can therefore be recommended, especially in seasons and localities where heavy dropping may be expected, and when picking has to be postponed owing to shortage of labour or large acreage. When the picking period is likely to be long, it may be sufficient to spray only those trees that will be picked last.

Conference pear responded well to the spray in 1942, when picking was postponed for a fortnight, but this variety showed little tendency towards a serious drop up to the normal picking date either in 1942 or 1943. The spray would probably be of value for this variety in localities where it tends to drop heavily, or when, for any reason, picking has to be delayed. Obviously, the spray must not be used to keep fruit on the trees beyond the date when they are

in a proper condition for picking, for over-maturity is even more dangerous in pears than in apples.

The experiments with Cox's Orange Pippin were designed for the control of oil-induced drop rather than of pre-harvest drop, the sprays were therefore put on very early in the season. No such drop happened to occur in the seasons concerned, so, from this standpoint, the experiments were inconclusive. There was some indication, however, that the growth substance sprays exerted considerable control over normal drop. The 1945 experiment was inconclusive as no pre-harvest drop developed. The sprays may prove of value with this variety in localities where drop is liable to be severe, but no definite recommendations are justified until further trials have been made with sprays applied at the appropriate time for control of pre-harvest drop. This variety, however, often drops very heavily early in the season ; this is probably not a true pre-harvest drop, and it is likely that the substances at present in use may prove to exert little control of it.

An appreciable gain in crop was secured in Bramley's Seedling in 1942 and 1943 by an application of growth substance spray a few weeks before the picking date. Both α-naphthaleneacetic acid and α-naphthalene acetamide were tried in 1942 and they proved equally effective. This variety showed a fairly uniform, low rate of drop over a period lasting several months. Though the cumulative effect of this drop may be considerable, it may prove difficult to encompass a sufficient portion of it within the effective period of a spray, to render spraying worth while. A very early spray, applied mixed with the last lead arsenate spray in June in 1943, had no effect on drop. Largely owing to a shortage of substance, the sprays were used at a rather lower concentration—6 or $7\frac{1}{4}$ p.p.m.—than is usually recommended for a late-maturing variety, and in rather small quantities for the size of the crop. An experiment in 1945, however, with a spray at a concentration of 10 p.p.m. gave practically no control of drop, and an application of the growth substance in the form of dust proved completely ineffective. In view of these results, spraying Bramley's Seedling cannot at present be recommended.

In general it may be said that these growth substance sprays are likely to be of use under English conditions, especially for certain varieties that tend to drop heavily, and when picking has to be postponed, but that further work on the subject is required.

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SUMMARY.

1. Sprays containing α-naphthaleneacetic acid, at concentrations ranging from $2\frac{1}{2}$ to 10 parts per million, have been tried on five varieties of apple and one of pear, in experiments spread over five seasons.

2. A large, significant gain in crop was obtained with Beauty of Bath, Miller's Seedling and Worcester Pearmain apples. Conference pear also responded well when picked late. Use

of the sprays with these varieties is recommended. Some response was obtained with Cox's Orange Pippin and Bramley's Seedling, but further tests are required before routine spraying of these varieties can be recommended.

3. Where two concentrations, 2½ and 5 p.p.m., or 5 and 10 p.p.m., were compared they gave similar results but, to ensure the best chances of success, 10 p.p.m. is recommended, though 5 p.p.m. may be sufficient for summer varieties in hot weather.

4. It is important to time the application of the spray so that its effective period covers the time when drop is likely to be most severe. Ten days to one month before the picking date seems usually to be about right.

5. It is suggested that dropping tendency during any period is best calculated by the use of the equation :

$$Q=100(\log_e X_1-\log_e X_2)/(t_2-t_1)$$

where X_1 and X_2 are the residual numbers, or percentages, of fruits on the trees at times t_1 and t_2, (t_2-t_1) is the time interval in days, and Q is the required index of dropping rate.

6. It is suggested, further, that the most convenient index of spray effect is that calculated from the equation :

$$q=100\ (Q_c-Q_s)/Q_c$$

where Q_c and Q_s are the dropping rates for control and sprayed trees and q is the required index of spray effect.

7. A conversion table for easy calculation of values of Q, from values of summed percentage drops, is given in the Appendix.

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APPENDIX.

Table for converting " Drops ", at simple, into " Rates ", at compound interest.

Marginal values represent " Accumulated Percentage Drops " ; internal values are the corresponding quantities at compound interest. Suppose that the values at t_1 and t_2 are 14·8 and 38·1 respectively, the corresponding values are 16·0 and 48·0 respectively. Suppose the time interval $(t_2 - t_1)$ is 3 days. The " Percentage Drops per day " at simple interest = $(38\cdot1 - 14\cdot8)/3$, that is 7·8 per cent. The corresponding value of the " Rate of Drop per day " at compound interest is $(48-16)/3$ or 10·7 per cent.

	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9
0 ..	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9
1 ..	1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9
2 ..	2·0	2·1	2·2	2·3	2·4	2·5	2·6	2·7	2·8	2·9
3 ..	3·0	3·2	3·3	3·4	3·5	3·6	3·7	3·8	3·9	4·0
4 ..	4·1	4·2	4·3	4·4	4·5	4·6	4·7	4·8	4·9	5·0
5 ..	5·1	5·2	5·3	5·4	5·6	5·7	5·8	5·9	6·0	6·1
6 ..	6·2	6·3	6·4	6·5	6·6	6·7	6·8	6·9	7·0	7·1
7 ..	7·3	7·4	7·5	7·6	7·7	7·8	7·9	8·0	8·1	8·2
8 ..	8·3	8·4	8·6	8·7	8·8	8·9	9·0	9·1	9·2	9·3
9 ..	9·4	9·5	9·7	9·8	9·9	10·0	10·1	10·2	10·3	10·4
10 ..	10·5	10·6	10·8	10·9	11·0	11·1	11·2	11·3	11·4	11·5
11 ..	11·7	11·8	11·9	12·0	12·1	12·2	12·3	12·4	12·6	12·7
12 ..	12·8	12·9	13·0	13·1	13·2	13·4	13·5	13·6	13·7	13·8
13 ..	13·9	14·0	14·2	14·3	14·4	14·5	14·6	14·7	14·8	15·0
14 ..	15·1	15·2	15·3	15·4	15·5	15·7	15·8	15·9	16·0	16·1
15 ..	16·3	16·4	16·5	16·6	16·7	16·8	17·0	17·1	17·2	17·3
16 ..	17·4	17·6	17·7	17·8	17·9	18·0	18·2	18·3	18·4	18·5
17 ..	18·6	18·8	18·9	19·0	19·1	19·2	19·4	19·5	19·6	19·7
18 ..	19·8	20·0	20·1	20·2	20·3	20·5	20·6	20·7	20·8	20·9
19 ..	21·1	21·2	21·3	21·4	21·6	21·7	21·8	21·9	22·1	22·2
20 ..	22·3	22·4	22·6	22·7	22·8	22·9	23·1	23·2	23·3	23·4
21 ..	23·6	23·7	23·8	24·0	24·1	24·2	24·3	24·5	24·6	24·7
22 ..	24·8	25·0	25·1	25·2	25·4	25·5	25·6	25·7	25·9	26·0
23 ..	26·1	26·3	26·4	26·5	26·7	26·8	26·9	27·0	27·2	27·3
24 ..	27·4	27·6	27·7	27·8	28·0	28·1	28·2	28·4	28·5	28·6
25 ..	28·8	28·9	29·0	29·2	29·3	29·4	29·6	29·7	29·8	30·0
26 ..	30·1	30·2	30·4	30·5	30·7	30·8	30·9	31·1	31·2	31·3
27 ..	31·5	31·6	31·7	31·9	32·0	32·2	32·3	32·4	32·6	32·7
28 ..	32·9	33·0	33·1	33·3	33·4	33·5	33·7	33·8	34·0	34·1
29 ..	34·2	34·4	34·5	34·7	34·8	35·0	35·1	35·2	35·4	35·5
30 ..	35·7	35·8	36·0	36·1	36·2	36·4	36·5	36·7	36·8	37·0
31 ..	37·1	37·3	37·4	37·5	37·7	37·8	38·0	38·1	38·3	38·4
32 ..	38·6	38·7	38·9	39·0	39·2	39·3	39·5	39·6	39·7	39·9
33 ..	40·0	40·2	40·3	40·5	40·7	40·8	40·9	41·1	41·2	41·4
34 ..	41·6	41·7	41·9	42·0	42·2	42·3	42·5	42·6	42·8	42·9
35 ..	43·1	43·2	43·4	43·5	43·7	43·9	44·0	44·2	44·3	44·5
36 ..	44·6	44·8	44·9	45·1	45·3	45·4	45·6	45·7	45·9	46·0
37 ..	46·2	46·4	46·5	46·7	46·8	47·0	47·2	47·3	47·5	47·6
38 ..	47·8	48·0	48·1	48·3	48·5	48·6	48·8	48·9	49·1	49·3
39 ..	49·4	49·6	49·8	49·9	50·1	50·3	50·4	50·6	50·7	50·9
40 ..	51·1	51·2	51·4	51·6	51·8	51·9	52·1	52·3	52·4	52·6
41 ..	52·8	52·9	53·1	53·3	53·4	53·6	53·8	54·0	54·1	54·3
42 ..	54·5	54·6	54·8	55·0	55·2	55·3	55·5	55·7	55·9	56·0
43 ..	56·2	56·4	56·6	56·7	56·9	57·1	57·3	57·4	57·6	57·8
44 ..	58·0	58·2	58·3	58·5	58·7	58·9	59·1	59·2	59·4	59·6
45 ..	59·8	60·0	60·1	60·3	60·5	60·7	60·9	61·1	61·2	61·4
46 ..	61·6	61·8	62·0	62·2	62·4	62·5	62·7	62·9	63·1	63·3
47 ..	63·5	63·7	63·9	64·1	64·2	64·4	64·6	64·8	65·0	65·2
48 ..	65·4	65·6	65·8	66·0	66·2	66·4	66·6	66·7	66·9	67·1
49 ..	67·3	67·5	67·7	67·9	68·1	68·3	68·5	68·7	68·9	69·1

	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9
50 ..	69·3	69·5	69·7	69·9	70·1	70·3	70·5	70·7	70·9	71·1
51 ..	71·3	71·5	71·7	71·9	72·2	72·4	72·6	72·8	73·0	73·2
52 ..	73·4	73·6	73·8	74·0	74·2	74·4	74·7	74·9	75·1	75·3
53 ..	75·5	75·7	75·9	76·1	76·4	76·6	76·8	77·0	77·2	77·4
54 ..	77·7	77·9	78·1	78·3	78·5	78·7	79·0	79·2	79·4	79·6
55 ..	79·9	80·1	80·3	80·5	80·7	81·0	81·2	81·4	81·6	81·9
56 ..	82·1	82·3	82·6	82·8	83·0	83·2	83·5	83·7	83·9	84·2
57 ..	84·4	84·6	84·9	85·1	85·3	85·6	85·8	86·0	86·3	86·5
58 ..	86·8	87·0	87·2	87·5	87·7	87·9	88·2	88·4	88·7	88·9
59 ..	89·2	89·4	89·6	89·9	90·1	90·4	90·6	90·9	91·1	91·4
60 ..	91·6	91·9	92·1	92·4	92·6	92·9	93·1	93·4	93·6	93·9
61 ..	94·2	94·4	94·7	94·9	95·2	95·5	95·7	96·0	96·2	96·5
62 ..	96·8	97·0	97·3	97·6	97·8	98·1	98·3	98·6	98·9	99·2
63 ..	99·4	99·7	100·0	100·2	100·5	100·8	101·1	101·3	101·6	101·9
64 ..	102·2	102·4	102·7	103·0	103·3	103·6	103·8	104·1	104·4	104·7
65 ..	105·0	105·3	105·6	105·8	106·1	106·4	106·7	107·0	107·3	107·6
66 ..	107·9	108·2	108·5	108·8	109·1	109·4	109·7	110·0	110·3	110·6
67 ..	110·9	111·2	111·5	111·8	112·1	112·4	112·7	113·0	113·3	113·6
68 ..	113·9	114·3	114·6	114·9	115·2	115·5	115·8	116·2	116·5	116·8
69 ..	117·1	117·4	117·8	118·1	118·4	118·7	119·1	119·4	119·7	120·1
70 ..	120·4	120·7	121·1	121·4	121·7	122·1	122·4	122·8	123·1	123·4
71 ..	123·8	124·1	124·5	124·8	125·2	125·5	125·9	126·2	126·6	126·9
72 ..	127·3	127·7	128·0	128·4	128·7	129·1	129·5	129·8	130·2	130·6
73 ..	130·9	131·3	131·7	132·1	132·4	132·8	133·2	133·6	133·9	134·3
74 ..	134·7	135·1	135·5	135·9	136·3	136·6	137·0	137·4	137·8	138·2
75 ..	138·6	139·0	139·4	139·8	140·2	140·6	141·1	141·5	141·9	142·3
76 ..	142·7	143·1	143·5	144·0	144·4	144·8	145·2	145·7	146·1	146·5
77 ..	147·0	147·4	147·8	148·3	148·7	149·2	149·6	150·1	150·5	151·0
78 ..	151·4	151·9	152·3	152·8	153·2	153·7	154·2	154·6	155·1	155·6
79 ..	156·1	156·5	157·0	157·5	158·0	158·5	159·0	159·5	160·0	160·4
80 ..	160·9	161·4	161·9	162·5	163·0	163·5	164·0	164·5	165·0	165·6
81 ..	166·1	166·6	167·1	167·7	168·2	168·7	169·3	169·8	170·4	170·9
82 ..	171·5	172·0	172·6	173·2	173·7	174·3	174·9	175·4	176·0	176·6
83 ..	177·2	177·8	178·4	179·0	179·6	180·2	180·8	181·4	182·0	182·6
84 ..	183·3	183·9	184·5	185·2	185·8	186·4	187·1	187·7	188·4	189·0
85 ..	189·7	190·4	191·1	191·7	192·4	193·1	193·8	194·5	195·2	195·9
86 ..	196·6	197·3	198·1	198·8	199·5	200·2	201·0	201·7	202·5	203·3
87 ..	204·0	204·8	205·6	206·4	207·1	207·9	208·7	209·6	210·4	211·2
88 ..	212·0	212·9	213·7	214·6	215·4	216·3	217·2	218·0	218·9	219·8
89 ..	220·7	221·6	222·6	223·5	224·4	225·4	226·3	227·3	228·3	229·3
90 ..	230·3	231·3	232·3	233·3	234·3	235·4	236·4	237·5	238·6	239·7
91 ..	240·8	241·9	243·0	244·2	245·3	246·5	247·7	248·9	250·1	251·3
92 ..	252·6	253·8	255·1	256·4	257·7	259·0	260·4	261·7	263·1	264·5
93 ..	265·9	267·4	268·8	270·3	271·8	273·3	274·9	276·5	278·1	279·7
94 ..	281·3	283·0	284·7	286·5	288·2	290·0	291·9	293·7	295·7	297·6
95 ..	299·6	301·6	303·7	305·8	307·9	310·1	312·4	314·7	317·0	319·4
96 ..	321·9	324·4	327·0	329·7	332·4	335·2	338·1	341·1	344·2	347·4
97 ..	350·7	354·0	357·6	361·2	365·0	368·9	373·0	377·2	381·7	386·3
98 ..	391·2	396·3	401·7	407·5	413·5	420·0	426·9	434·3	442·3	451·0
99 ..	460·5	471·1	482·8	496·2	511·6	529·8	552·1	580·9	621·5	690·8

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AN EXPERIMENT ON THE CONTROL OF PEAR MIDGE *(CONTARINIA PYRIVORA)*

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Pear Midge is a widespread pest in both the U.S.A. and Great Britain. In this country the infestations are local, in that they are often confined to certain orchards or even to particular trees. At times susceptible varieties of pears in private gardens suffer a nearly complete loss of crop. In old established farm orchards in the West Country it has been noticed that the infestation may be confined for years to individual trees. In commercial orchards the infestation is generally most severe on Williams' Bon Chrétien ; on the other hand, for incompletely understood reasons, the attack in some seasons may be widespread over a wide range of varieties, though Williams' remains the most severely affected.

Pear Midge occurs on trees on both heavy clays and light sandy soils. The midges are on the wing from before white bud until the open flower stage. At times they may be found resting on the wood of the trees, and occasionally, on very still days, they may be observed flying between the branches. The eggs are laid in numbers in the flower buds and open flowers ; the optimum time for oviposition has not been ascertained in this country but observations suggest that numbers of eggs are deposited in the early white bud stage. As soon as the larvae hatch they bore their way into the developing fruitlets and cause the development of a characteristic malformation consisting of a flatness at the calyx end. This permits of easy recognition of infested fruitlets at an early stage ; later, these fruitlets enlarge much more rapidly than the unattacked ones.

When the larvae are nearly full-grown, about six weeks after hatching, the fruitlets fall to the ground and the larvae escape from the rotting tissue ; or, the larvae may fall to the ground after escaping from cracks which develop in the fruitlets still on the tree. On reaching the ground the larvae find their way into the top inch or so of the soil where they pupate, mostly in the autumn. From the puparia on or near the surface of the soil the midges emerge in spring. It is possible that some of the puparia remain in the soil for two seasons (1).

It has been stated that repeated cultivations of arable soils during the period of 4-6 weeks immediately following the dropping of infested fruitlets provide a reasonably effective control. This method can be relied on only where the cultivations involve the whole of the area of soil beneath the spread of the tree, a procedure that is not always practicable. Moreover, it is not outstandingly successful on heavy soils and cannot be applied in grass orchards. Staniland and Walton (2) found that calcium cyanide dug into arable soils beneath infested trees provided an appreciable control. This method in commercial practice, however, gives very variable results and on heavy soils frequently fails. Nicotine wash applied to the open blossom was also found to give a marked reduction in attack. Unpublished data by the present writers showed that more consistent results were obtained by heavy application of nicotine washes at the early white bud stage at the time when the midges had emerged in numbers and were either on or flying about the trees. A heavy application of a 20 per cent. concentration of a tar oil emulsion in September was ineffective, but it was found that the complete removal of soil from beneath infested trees to a depth of 4 in. provided control (2).

It was noticed by Mr. K. Bomford in 1943 that infestations were less on trees sprayed with DNC petroleum wash just before bud burst, and to follow up this observation experiments were arranged in 1944 to ascertain the value of soil treatments with tar oil and DNC petroleum washes as means of control.

MATERIALS AND METHODS.

A block of 201 Williams' Bon Chrétien and 114 Fertility trees, trained as espaliers and planted 12 ft. by 13 ft. apart on a light gravelly soil derived from Bunter Drift material, was selected for an experiment. The plantation, which was under a system of arable culture, was divided into 15 plots of equal size, each containing from 18 to 24 trees of the two varieties. Five randomized treatments, each in triplicate, were given as follows:

(1) Tar oil emulsion applied to the soil at bud burst.
(2) DNC petroleum emulsion applied as in (1).
(3) Tar oil emulsion applied to the soil 4 to 5 days before the white bud stage.
(4) DNC petroleum emulsion applied as in (3).
(5) Untreated control.

The tar oil emulsion was applied at a concentration of 3 per cent. high-boiling, neutral tar oil, and the DNC emulsion at a concentration of 0·1 per cent. dinitro-ortho-cresol and 5 per cent. petroleum oil Grade E. Both washes were prepared as sulphite lye emulsions (3 and 4).

The bud burst applications were made on 1/3/44, and the pre-white bud applications on 27/3/44, when only an occasional central flower of the bud cluster of the Williams' trees showed a portion of white petal. The Fertility buds were slightly less advanced. The washes were applied to the soil from a mobile spraying machine by means of two manually operated nozzle spray brooms operating at approximately 200-250 lb. per sq. in. The low pressure avoided drift on to the trees. The entire surface of soil was sprayed at the rate of 900-1,200 gallons per acre. With the type of spray equipment used it was difficult to apply an equal volume to each plot. The soil was dry for both applications and the top layer absorbed the washes.

TABLE I.

Variety.	Treatment.	Total No. fruitlets.	No. of infested fruitlets.	% infestation.	Harvested pears per tree.			
					No.	% increase over control.	Weight lb.	% increase over control.
Williams' Bon Chrétien	Tar oil at bud burst.	4,638	223	5	478	10	88	53
	Tar oil at early white bud.	5,117	376	7	410	72	80	39
	DNC at bud burst (a)	1,942	173	9	424	78	86	50
	DNC at bud burst (b)	3,822*	793	21	—	—	—	—
	DNC at early white bud.	6,010	594	10	349	46	75	31
	Control.	5,000	3181	64	239	—	58	—
Fertility	Tar oil at bud burst.	2,364	7	0·3				
	Tar oil at early white bud.	3,312	7	0·2				
	DNC at bud burst.	4,000	31	0·8				
	DNC at early white bud.	3,954	40	1·0				
	Control.	4,057	390	9·6				

* Approximately only 750 gallons applied instead of 1,000.

RECORDING OF DATA.

In two of the three replicates of each treatment approximately 1,500-3,000 total fruitlets selected at random were examined on May 11th and 12th. At picking time the crop weights and numbers of fruits were recorded on the Williams' trees only, as the infestation on the Fertility trees was not sufficiently high to make this worth while.

RESULTS.

The figures adjusted to the nearest whole number for Williams' for infested fruitlets of both varieties and for harvested pears of Williams' are summarized in Table I. It was evident from this preliminary experiment that the application of the tar oil and the DNC petroleum emulsions provided a high degree of control. Analysis of variance of the results from treated plots revealed no significant differences in control due either to times of application or to the two washes. Whether or not the apparent superiority of the tar oil wash over the DNC wash is real, can be determined only by further and more detailed trial. A further point for investigation is the apparent improvement in control due to heavier application, namely DNC at " bud burst " on Williams'.

The increases in total crop were accompanied by decreases in the size of the individual fruits. It would have been necessary to thin the crops where the spray treatments were given if fruits of large size had been required. General observations suggested that if the trees are well grown and give promise of bearing a heavy crop of blossom they may be able to withstand up to 75-80 per cent. infestation of blossom without serious loss in fruit crop weight.

SUMMARY.

1. A preliminary trial showed that tar oil and DNC petroleum emulsions applied to the soil at the rates of 900-1,200 gallons per acre between bud burst and immediately before the white bud stage provided a high control of Pear Midge, (*Contarinia pyrivora*).

2. The treatments, with an infestation of 64 per cent. of fruitlets, provided 46-101 per cent. increase in numbers of fruits harvested and 31-53 per cent. increase in crop weight.

3. The increase in numbers of harvested fruits resulted in smaller sized pears, and to obtain large fruits it would have been necessary to thin the crops when the soil treatments were carried out.

ACKNOWLEDGMENTS.

Best thanks are due to Mr. K. Bomford, Harvington Lodge, Evesham for providing the necessary facilities for the trial, and to Dr. H. Martin for statistical analysis of the data.

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PEAR BLOSSOM BLIGHT

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In recent years a bacterial blight of pear blossoms has been observed in the east and south-east of England and has been studied chiefly in relation to its occurrence on the trial plots at the East Malling Research Station, where it was first noticed as causing appreciable damage on a number of varieties in 1929. It was more severe and widespread the following year, and during the last fifteen years it has been seen frequently, being generally most severe in years when there was cold wet weather as the trees were coming into blossom.

Thus, in 1941, the spring was wet, with low temperatures, and pear Blossom Blight was general ; on some trees nearly all the blossom was blackened and killed. The spring of 1942 was much drier and there was but little Blossom Blight. In that year, blackened flower trusses, as well as others not showing the discoloration, were covered with a sticky film, and some of the buds were sealed up with it. This was associated with an attack of Apple Blossom Weevil, and it would seem that at times the weevil's punctures aid in starting attack by the Blossom Blight organism ; for, as shown by inoculation experiments, infection occurs most readily when the outer tissues are injured.

From observations at East Malling, and from the examination of specimens from elsewhere, the most susceptible varieties among those most commonly grown appear to be Durondeau, Pitmaston Duchess, Marie Louise and Catillac, but severe attacks have been seen on Conference, Hessle, Alexander Lucas, Emile d'Heyst, Beurré d'Amanlis and Fondante de Thirriott.

On a cordon trial plot certain varieties were badly damaged in 1933. Some trees of Durondeau, Fondante d'Automne, Emile d'Heyst, and Duchess de Bordeaux had all their blossoms killed.

The symptoms vary with the severity of attack. Some affected flowers show blackened spots or bands (girdling, or on one side only) on the receptacle, while styles and disc are still normal. In very many affected flowers the blackening extends completely around the receptacle and down the pedicel for various distances (Plate I, Fig. 1). On some inflorescences the peduncle is blackened and the whole truss (flowers and leaves) withered (Plate I, Fig. 2).

On Catillac pear three stages were observed towards the end of May, 1936, a year of severe infection : (*a*) flowers killed and pedicels blackened, but discoloration not extending into the peduncle ; (*b*) unopened buds swollen but quite dead, and discoloration extending into the spurs ; (*c*) whole trusses killed and discoloration extending to the base of the inflorescences and into tissues of the spurs.

Usually infection is limited to the young tissues of the current year's growth, but sometimes it proceeds into the older tissues of the spur, and in one outbreak it had reached the branches to form cankers.

When the tissues of the blackened parts are teased out in water, swarms of bacteria exude and the organism can easily be isolated. Plates prepared in the early stages of attack usually yield colonies of one particular organism, but plates from tissues that have been withered for some time often show a mixture of several organisms, indicating that the tissues have been invaded by saprophytes.

Many isolates have been obtained from affected inflorescences of various varieties of pear from a number of sources. The medium used for the initial isolations has been nutrient agar containing 5 per cent. saccharose, for this shows certain colony characters not clearly seen in plain nutrient agar. On this sugar medium the colonies that most frequently appear show distinct radial lines when examined under a low power of the microscope. In poured plates the colonies of this organism are of three forms, according to their situation in the

medium. The surface colonies in 2 or 3 days are raised and almost hemispherical, the embedded colonies are lenticular and rather dense, and the basal colonies (situated where the medium comes in contact with the dish) are thin and delicate. All three forms show the radial structure clearly.

Another type of colony that sometimes appears in pure or almost pure cultures on isolation plates is easily distinguished from the above. No radial lines are seen (or a few very faint streaks may sometimes be detected), and the whole colony is minutely granular only ; these surface colonies are almost flat, but sometimes slightly umbonate. On one occasion isolation yielded colonies with similar structure but having a yellowish tint.

Thus, three organisms, referred to here as *A*, *B*, and *C*, have been isolated and all three have been proved by inoculation experiments to be pathogenic. In addition to the characters of the colonies the three may be distinguished in other ways. The chief diagnostic characters may be tabulated as follows :

	Colonies on nutrient agar +5% saccharose.	Growth in nutrient broth +5% saccharose.	Growth on potato dextrose agar.
A	White, raised, nearly hemispherical ; radial lines clearly shown.	Cloudy, with a faint yellowish tint.	Whitish or grey, not pigmented.
B	Whitish or grey, almost flat, uniformly finely granular.	Yellowish, translucent.	Whitish or grey, not pigmented.
C	Yellowish, almost flat, uniformly finely granular.	Yellowish, translucent.	Blue green.

As type *A* has been most frequently obtained, and is considered to be the chief cause of the disease, it has received most attention. The radial lines of the colonies recalled the similar structure shown by *Pseudomonas prunicola* and *P. mors-prunorum*, the two organisms causing bacterial diseases of stone-fruit trees (Wormald, 1930, 1932) ; so the tests used in distinguishing those two organisms were applied. The pear organism was found to give a yellowish tint in nutrient broth with 5 per cent. saccharose, and in Uschinsky's solution ; to be viable after 6 days when incubated on nutrient agar+5 per cent. saccharose ; and to give only an alkaline reaction on nutrient agar+2 per cent. lactose.* These characters are those of *P. prunicola* and not of *P. mors-prunorum*.

Type *A* agrees with *P. prunicola* in other characters. It is a short rod, Gram negative, without spores or capsules and with 1-3 polar flagella. In nutrient broth at 25° C. it produces, within 2 days, a pellicle which readily fragments ; in Uschinsky's solution it develops a pellicle which fragments or sinks as a whole ; it does not reduce nitrate and has no diastatic action ; it slowly liquefies gelatin, produces acid but no gas from dextrose and saccharose and no acid from lactose. In media containing glycerin the results have been somewhat variable but generally it produces no acid (or only a trace) and no gas. From these characters its Group Number becomes 211.2322033.

Isolates showing these characters have been obtained not only from infected flowers but also from pear leaf spots and fruit spots. The leaf spots may be numerous and small (Plate II, Fig. 4), or few and large ; the larger spots are each encircled by a pale yellowish zone (Plate II, Fig. 5).

* Two isolates of *A* type out of 14 tested on this medium, have in some tests, not in others, changed the reaction from alkaline to acid.

The bacterial spotting of pear fruits appears to be unusual. It has been seen only once, in 1936, on Fertility pears received from Teynham, in north Kent. The spots were 0·5–2 mm. in diameter; they had a greyish raised centre with a dark line around it, then an irregular grey line; in the larger spots this was encircled by a black zone (Plate II, Figs. 6 and 7). The organism isolated from the spots was inoculated into pears and within 5 days it had produced blackened, slightly sunken (saucer-shaped) spots 1·5–3·5 cm. in diameter. The organism was re-isolated from the spots.

Inoculations with isolates from pear blossoms, through punctures into pear fruits either on the trees in the open or in a moist chamber under laboratory conditions, have produced black sunken lesions within a few days. As results of inoculations on the fruit are more consistently positive than those made on flowers or inflorescences they serve as a useful diagnostic test (Plate II, Fig. 8). In one experiment the primary lesion became surrounded by smaller black spots, suggesting infection through the lenticels without wounding.

Inoculations on pear flowers in the open without wounding have, up to the present, given negative results, but infection has been obtained by inoculations through punctures into the receptacle (calyx cup) of individual flowers, and into the peduncle of inflorescences.

In inoculations of pear flowers using an isolation of *A* and one of *B* there was blackening around the punctures within 2 days, and lesions 2 mm. across in 3 to 5 days. In these experiments the discoloration extended into the pedicels, but the flowers fell before infection passed into the peduncles. Isolations from infected flowers yielded the type of organism inoculated into the particular flowers.

Inoculations on peduncles with three isolations of *A*, one of *B*, and one of *C*, resulted in black lesions, some of them girdling the peduncle and causing the whole truss of flowers to turn black. Lesions 2–8 mm. long developed within 12 days, and wilting of the inflorescences in 20 days; in one of them wilting had occurred by the twelfth day (Plate I, Fig. 3). Re-isolations from wilted trusses were made, and the organism recovered in each case was identical with the particular type used in the inoculation.

In the same way positive results on inflorescences were obtained with the *A* type isolated from a pear fruit spot, with *P. prunicola* from a plum shoot, and with *P. prunicola* from a cherry leaf spot.

From the cultural and inoculation experiments it can be concluded, therefore, that the *A* type pear Blossom Blight organism is indistinguishable from *Pseudomonas prunicola*. The identity of the *B* and *C* types has not yet been determined.

Historical.

The most destructive bacterial disease of pear trees is Fire Blight, and the organism causing it (*Bacillus amylovorus*) has received much attention, particularly in North America. Other organisms, however, have been shown to induce a blossom blight, or blast, of pears, and, though not so harmful as *B. amylovorus* they cause at times considerable damage.

A bacterial disease of pear blossoms observed at the Long Ashton Research Station was recorded by Barker (1913), and the organism causing it was described, but not named, by Barker and Grove (1914*a* and *b*) and by Grove (1918).

In 1918 Doidge described a pear blossom disease in South Africa. The organism isolated from infected flowers was examined in parallel tests with an isolation of Barker and Grove's organism, and its characters were compared with those in published accounts of *Bacillus amylovorus*. The South African organism appeared to be one not previously described, so it was named *Bacterium nectarophilum* with the group number 222.2332123. The group number of Barker and Grove's organism (left unnamed) was given by Doidge as 221.3332123; the 0·3 shows that it does not produce acid from dextrose, a character in which it differs from both *B. nectarophilum* and *P. prunicola*; it also has a relatively low (about 18° C.) optimum

temperature. *B. nectarophilum* does not liquefy gelatin, while the other two both cause liquefaction.

In 1924 Berridge, using Barker and Grove's organism among others in certain tests, referred to it as " Bacillus Barkeri " but without attaching any description to it. Since that time the specific epithet *barkeri* has been generally adopted (Elliott, 1930 ; Bergey *et al.*, 1939) for this organism with the characters as given by Doidge.

Blossom blast of pears in the United States was first described by Clara (1932) who attributed the disease to an organism named by him *Pseudomonas utiformica*. Rosen and Bleecker (1933) concluded that *P. utiformica*, *P. cerasi*, *P. prunicola*, *P. nectarophilum* and *P. barkeri* should all be included under *P. syringae*, the lilac blight organism. Wilson (1936), from results of cultural and infection tests, found that certain pear blast isolates resembled *Phytomonas cerasi* (Griffin) Bergey *et al.* (=*Pseudomonas cerasus* Griffin) in producing a green pigment on potato dextrose agar, while others, which did not produce this pigment, resembled *Phytomonas cerasi* var. *prunicola* (=*Pseudomonas prunicola*). He was of the opinion, however, that both these, as well as *P. utiformica*, were so similar to *P. syringae* that they should be included in this species. More recently Reid *et al.* (1942), from serological studies, have suggested that *P. cerasi* and *P. syringae* are identical with the common saprophyte *P. fluorescens*.

Whether some or all of these organisms should be included under a particular name is a matter of personal opinion, based on the results of the particular line of research of the investigator. It may be pointed out, however, that, of the organisms studied by the writer, one (the *A* type) conforms with *Pseudomonas prunicola*, and another (*C*), from its pigmentation on potato dextrose agar, *may* be *P. cerasi*. The two types *A* and *C* can readily be distinguished not only on potato dextrose agar but also from the contour of the colonies on nutrient agar containing 5 per cent. saccharose, and in the appearance of the growth in nutrient broth containing 5 per cent. saccharose ; in the latter medium *P. prunicola* produces a distinct cloudy growth with a yellowish tint, while with the *C* type the liquid is hardly cloudy but retains a characteristic translucency. Whether *P. cerasi* Griffin has these other *C* type characters has not yet been determined.

As shown above, three pathogenic organisms isolated from pear blossoms in south-east England can be distinguished by simple cultural tests. These three would appear also to show divergence in certain characters from both *Pseudomonas nectarophilum* and *P. barkeri*. Until more is known about the characters and host range of these organisms it seems preferable, in the opinion of the writer, to regard them, if not as distinct species, at least as sub-species or varieties of a previously named species, otherwise confusion may arise. In a recent note (Oxford, 1944) eight isolations from pear (obtained from the present writer, under serial numbers and unnamed) were all included under *Ps. syringae*, thus assuming their identity with the lilac organism ; five of these were of the *A* (*prunicola*) type, two were of *C* type and its re-isolation, and the other was one received from the Lister Institute as " Bacillus Barkeri."

Suggestions for control.

It is not known how the organisms here described reach and enter the flowers to cause infection. There seem to be two possible ways : either they overwinter in the dead spurs, as is stated for *Bacillus barkeri* (Barker and Grove, 1914*a*), and the bacteria are washed down by rain on to the bursting flower buds, or they reach the young buds as these develop, during spring, and spend the summer and winter there. Since the bacteria multiply rapidly in the tissues of affected flowers, any new infection increases the numbers of infective bacteria. All infected inflorescences should therefore be removed from the tree as soon as possible after an outbreak has been noticed. It is not known whether a pre-blossom bactericidal spray has any effect on the incidence of the disease. Insects that would puncture the flowers should be kept under control by the ordinary routine measures. The trees should be kept open by

PLATE I.

Fig. 1.
Pear Blossom Blight: natural infection of flowers.

Fig. 2.
Severe natural infection of inflorescences.

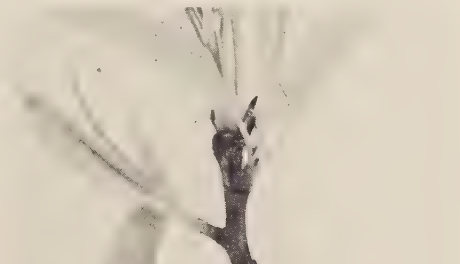


Fig. 3.
Inflorescence on right inoculated (with an isolate of *A* type) on peduncle: result on 13th day.

[*face p.* 44

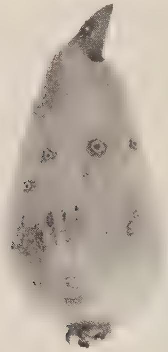
PLATE II.

4

FIG. 4.
Pear Bacterial Leaf Spot: spots many and small.

5

FIG. 5.
Pear Bacterial Leaf Spot: spots few and large.



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FIGS. 6 and 7.
Bacterial Fruit Spot.

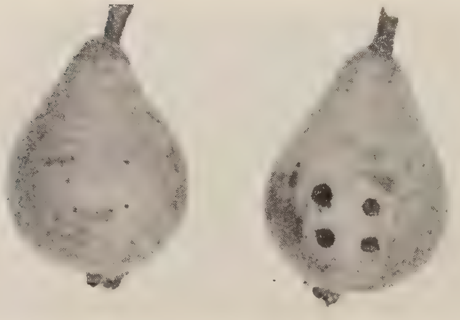

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FIG. 8.
Pear on right 6 days after inoculation; control on left.

judicious pruning so as to avoid, as far as possible, retention of moisture on the opening buds.

ACKNOWLEDGMENT.

The writer is indebted to Dr. H. B. S. Montgomery for assistance in isolation and inoculation experiments, and for the photograph shown in Fig. 5.

SUMMARY.

A Blossom Blight of pears in east and south-east England is described. Three pathogenic organisms have been isolated from affected blossoms ; the one of most frequent occurrence is found to be indistinguishable from *Pseudomonas prunicola*, one of the organisms causing bacterial infection of plum and cherry trees. A brief historical survey of previous work on closely allied bacteria is given and control measures are suggested.

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FROST INJURY TO APPLES

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EXTENSIVE damage to fruit crops was caused by late spring frosts in 1944, and as a result many orchards, especially those in low-lying situations lacking adequate air circulation, failed to crop.

At Merton, in Surrey, the frost was not so severe as at some other places. The temperatures at the critical period and immediately following it were:

Date.	Min. ground.	Min. screen.	Maximum.
May 6th	39° F.	41° F.	51° F.
,, 7th	**27**	**28**	**54**
,, 8th	**27**	**27**	**62**
,, 9th	**30**	**31**	**65**
,, 10th	39	39	68
,, 11th	40	41	74
,, 12th	44	44	75

At this time most varieties of apple at Merton had finished flowering, and the developing fruitlets were up to 8 mm. in diameter. Only a few secondary flowers still retained their petals.

Examination of the frost damage was made on the following fourteen Canadian apple varieties grown as bush and half-standard trees on a cultivated plot.

1. Emilia
2. Forpear
3. Fortosh
4. Joyce
5. Lawfam
6. Linda
7. Lobo
8. Macross
9. McSweet
10. Melba
11. Milton
12. Newtosh
13. Patricia
14. Pedro

Observations were made also on a bush tree of Red Victoria in an adjoining plot. Forty fruitlets per tree were collected from the tops of the trees. These were examined and the following three types of injury were observed:

(1) Loosening of the skin.
(2) Radial splitting of the cortex.
(3) Discoloration of the ovules and placenta.

The first and third types of frost injury had previously been observed, under laboratory conditions, by Field (1939).

(1) *Loosening of the skin* was the first and most common symptom of injury and was observed in all the varieties examined. Sometimes it was found on otherwise uninjured-looking fruitlets, and particularly on the ovaries of secondary flowers. Usually, however, it was accompanied by some internal discoloration. It was always present in fruitlets that showed radial splitting and general contraction, and was due to an irregular interrupted circular splitting of the cortex. The splitting took place through the thin-walled cells that lie below the thick-walled, tangentially stretched cells of the hypodermal layer (Plate I, Fig. 1).

It seems that the structural difference between these two types of cells was responsible for the occurrence of the fracture in this region. The fracture was probably caused either by greater contraction of the cortex than of the hypodermal layer, or by the accumulation of water withdrawn from the surrounding tissue, which, on freezing, tore the cell walls and lifted the skin; most probably both these factors were implicated. Ice formation inside apple fruitlets was reported by Dorsey (1938). The lifting of the skin in fruitlets is analogous to the lifting of the bark in a frost injured apple stem (Modlibowska

and Field, 1942), in which the line of splitting also passed through thin-walled cells (of cambium or undifferentiated cells) adjacent to the wood cylinder. Under favourable conditions, if no other injury accompanied the loosening of the skin, healing was rapid. Dorsey (1938) noticed recovery to begin in from 5 to 6 days. At Merton, in 1944, 3 days after the frost, the skin of most of the injured fruitlets was adhering firmly again.

Microscopical examination of sectioned fruitlets showed that the spaces beneath the lifted areas were filled with irregular, thin-walled callus cells, proliferating from both sides of the split (Plate I, Fig. 1). This tissue was delimited by darker, broken lines formed by the debris of torn cells. The easy and rapid recovery from loosening of the skin suggests that the frost damage was confined to mechanical fracture only. In the surrounding cells the low temperature did not cause any permanent change which inhibited their regenerating abilities.

(2) *Radial splitting of the cortex* of fruitlets was more serious. It was common in those of Red Victoria but seldom occurred in the Canadian varieties. It was caused by a strong tangential contraction of the cortex, in which radial splits usually ran between the vascular bundles. Their distal ends often united with the circular split which lifted the skin, their proximal ends sometimes reached the pith. The few radial splits that occurred opposite vascular bundles usually did not penetrate the bundles themselves (Plate I, Fig. 2). In some cases a layer of cells containing crystals also prevented the further elongation of a radial split (Plate I, Figs. 3 and 4). Radial splits in the cortex seldom healed, but some callusing was seen at their distal ends uniting with that of the healing splits beneath the lifted skin (Plate I, Fig. 5).

(3) *Discoloration of the internal tissue* of the fruitlets was relatively light ; comparatively few were severely injured and these dropped a few days after the frost damage. The less discoloured fruitlets appeared to recover, but many abscissed during the June drop.

Dark discoloration of the tissues was a more serious symptom. According to Steinmetz and Hilborn (1937) the protoplasts of the parenchyma cells of the apple stem killed by frost produce a gum-like substance which penetrates and blocks the vessels, thus killing the affected stem. In the severely frost-damaged fruitlets that showed brown discoloration of the tissues it is probable that a similar process took place. The ventral vascular bundles in the placenta were particularly liable to this injury, as the cells surrounding them were among the first to be injured.

The most severe injury was observed on the bush tree of Red Victoria. All its fruitlets were badly affected, showing, apart from complete loosening of the skin, many internal radial splits and deep brown discoloration of the ovules and placenta. Among the Canadian varieties examined, McSweet and Forpear were most affected, while Linda showed least damage. But even on the most injured trees at least 10 per cent. of undamaged fruitlets still remained. Hence, even in the most severe cases, the thinning of fruitlets by frost did not necessarily reduce the final crop of fruit.

RECOVERY OF FROST INJURED FRUITLETS.

The king fruitlets were considered separately. Of the remainder an average of 57 per cent. showed some internal discoloration due to frost (43 per cent. slightly, and 14 per cent. more heavily injured). (Table I.) The king fruitlets were, in general, affected to the same extent

TABLE I.

Frost injury to fruitlets of 14 apple varieties.

	No. examined.	Percentage.		
		Not injured.	Slightly injured.	Severely injured.
King fruitlets ..	70	44	44	12
Normal fruitlets ..	375	43	43	14
Secondary flowers ..	111	65	31	4

as the other fruitlets, viz. 56 per cent. (44 per cent. slightly and 12 per cent. severely injured). In the variety Lobo, however, 80 per cent. of the king fruitlets were discoloured (34 per cent. slightly and 46 per cent. severely). (Table II.) For the most part, the injury was not severe,

TABLE II.

Frost injury to fruitlets of the variety Lobo.

	No. examined.	Percentage.		
		Not injured.	Slightly injured.	Severely injured.
King fruitlets ..	35	20	34	46
Normal fruitlets ..	474	37	21	42
Secondary flowers ..	17	94	—	6

and in 63 per cent. of clusters at least one fruitlet in each was found unaffected. For this reason different rates of thinning of the fruitlets per cluster were applied to this variety in an attempt to ascertain whether the king fruitlet can recover and develop to maturity, and also whether its recovery is influenced by the number of fruitlets competing with it in a cluster. The thinning was done on May 12th, i.e. on the third day after the last frost. In some clusters all the fruitlets were removed except the king fruitlets. In others, one other fruitlet in addition to the king fruitlet was left. In the controls no fruitlets were removed.

Table III contains the data recorded both at the end of the so-called June drop and also at the time of fruit maturity. After the June drop the percentage of fruitlets set was inversely

TABLE III.

Fruit and seed set of frost injured fruitlets following thinning in the variety Lobo.

	Fruitlets left per cluster.		No fruitlets removed.	Only secondary fruitlets left.
	King fruitlet only.	King fruitlet and a lateral.		
Number of clusters	32	32	38	24
Total number of fruitlets	214	221	263	209
Number of fruitlets left	32	64	263	62
After June drop.				
Number of fruitlets	8	12	9	9
Percentage of fruitlets set	25	19	3	15
Percentage of clusters set	25	31	24	33
Number of abscissed fruitlets examined for seed content	2	6	33	1
Number of seeds per abscissed fruit.. ..	5·5	6·3	9·6	3·0
At Maturity.				
Number of fruits	4	10*	4	1
Percentage of fruits set	12	16	2	2
Percentage of clusters set	12	28	11	4
Number of seeds per fruit	8·7	9·1	9·7	7·0

* 2 were king fruits.

proportional to the number of fruitlets left per cluster at the time of thinning. This is the usual result when the drop of fruitlets is mainly due to nutritional competition. With more severe frost injury a direct correlation might be expected, as unthinned clusters would have a better chance of containing one comparatively uninjured fruitlet than those containing only

one or two fruitlets. Then nutritional competition would not be so acute because of the early drop of severely injured fruitlets. There was not much difference between treatments in the percentage of clusters that set fruit.

The seed content of a number of abscissing fruitlets was counted. Lobo usually contains a very large number of seeds per fruit, because it commonly develops four ovules per locule instead of the normal two (Plate I, Fig. 6). The seeds were flattened and practically empty, presumably owing to a starvation period preceding the drop. The high seed content of fruitlets abscissed from unthinned clusters (Table III), showed that pollination had been good and that the frost had not prevented the development of a large number of ovules.

The data recorded at the end of August show that many fruits fell from the trees after the June drop. The clusters that were thinned to two fruitlets were least affected by this later drop. The seed content was high in all cases, about nine per fruit.

From all these data it is evident that the king fruitlet, when left alone in the cluster, was capable of developing and reaching maturity in 12 per cent. of cases. When left with another fruitlet, however, the king fruitlet usually abscissed. In controls, with no fruitlets removed, no king fruitlets developed ; all of them abscissed during the June drop. This suggests that the king fruitlet was usually injured by frost to a degree that allowed for recovery only under favourable conditions. In competition with less injured or unaffected fruitlets the king fruitlet did not survive.

FROST INJURY TO SECONDARY FLOWERS.

In 1944 most varieties produced an appreciable number of belated, secondary flowers. These were smaller and arranged either singly or in twos and threes on long, thin, pedicels growing out from a normal cluster. Most of these flowers were open at the time of the frost. The difference in the stage of development between these flowers and the already formed fruitlets may account for the observed difference in degree of frost damage. It is generally accepted that an open flower is more resistant to low temperature than a young fruitlet of the same variety (Chandler, 1942, p. 119). Moreover, according to West and Edlefsen (1921), when the fruit is setting the injury is from 5 to 10 per cent. greater than when the flowers are in full bloom.

The secondary flowers of the Canadian varieties suffered more from loosening of the skin but less from discoloration of the ovules and placenta ; 65 per cent. of the flowers were free from internal discoloration, and among the injured only 4 per cent. were severely damaged (Table I). On June 16th, 15 per cent. of the fruitlets from secondary flowers remained on the trees (Table III). Later, however, the drop of fruitlets from secondary flowers was very severe and only one fruit (2 per cent.), containing seven seeds; reached maturity.

The relatively high set of fruit in June was probably due not so much to the less extent of frost damage suffered by the secondary flowers, as to their less advanced age causing some prolongation of their development beyond the normal June drop. This severe late drop was probably the result of less favourable conditions for pollination of the secondary flowers which were in bloom just before or during the frost period. Apart from this, the relatively small number of apple flowers open at that time might not have secured enough pollen to give a high seed set. Therefore the seed content of the secondary fruitlets was lower than that of the earlier developed ones.

SUMMARY.

Three types of frost injury were recorded on apple fruitlets following the frost in May, 1944 : (1) loosening of the skin, (2) radial splitting of the cortex and (3) discoloration of ovules and placenta. Loosening of the skin began to heal in most cases after about 3 days. Radial splitting was the most severe frost injury and was usually fatal. Recovery from internal

discoloration depended not only on its degree and extent but also on the nutritional condition of the injured fruitlets. This was shown by the failure to develop discoloured king fruitlets in unthinned clusters, but their ability to do so and to mature when all other fruitlets in a cluster were removed.

Secondary flowers were less injured by frost than the fruitlets from normal flowers, but in spite of this they rarely developed.

In general, the frost in May, 1944 did not greatly affect the ultimate crop of apples at Merton.

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PLATE I.

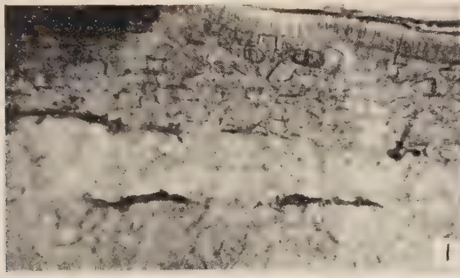

FIG. 1.

Callus formation between the lifted skin and the cortex. Above is the hypodermal layer and below this is the callus layer bordered by dark bands of broken cells. (×230)

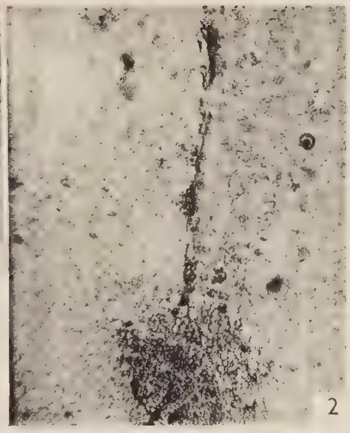

FIG. 2.

Proximal end of a radial split terminating at a vascular bundle. (×96)

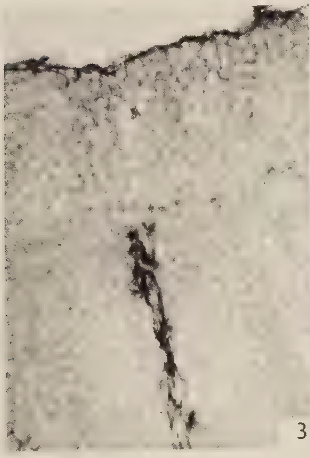

FIG. 3.

Distal end of a radial split terminating at a layer of cells containing crystals. (×96)

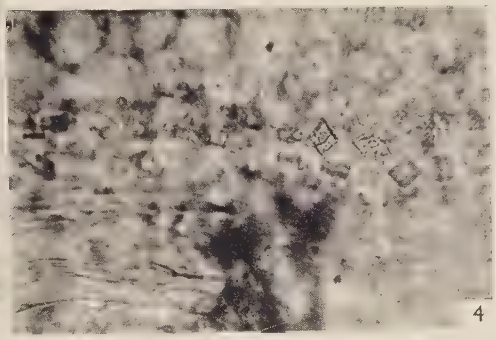

FIG. 4.

The layer of cells containing crystals shown in Fig. 3 (×230)

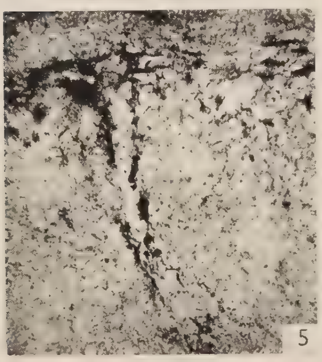

FIG. 5.

A radial split showing healing; the original dark band of broken cells is separated into two bands by callus formation. (×96)

FIG. 6.

Fruitlets of the variety Lobo. Upper one normal, 3 to 4 developing seeds per locule. Lower left, a frost injured normal fruitlet that abscissed. Lower right, an uninjured secondary fruitlet.

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STUDIES IN THE PHYSIOLOGY OF ROOTSTOCK AND SCION RELATIONSHIPS

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INTRODUCTION.

The influence of rootstock on scion, resulting in differences in tree size and precocity, has been established by the work of Hatton and his colleagues at East Malling. In spite of a continually increasing volume of evidence, however, the converse effect, namely that of scion on rootstock, is not so generally recognized. The present authors feel it necessary to emphasize the fact that rootstock and scion relationships are reciprocal in character, and that even in instances in which the rootstock does dominate a particular stock-scion combination, this state of affairs should not be allowed to obscure or lessen the importance of other instances in which the scion is the main factor that determines tree size, longevity and cropping capacity.

It is impossible to review the vast amount of literature on this subject at this point, but the question at issue is: Through what function of growth does the rootstock or the scion exercise control over the other part of the symbiotic unit? Rootstock effects may arise, (1) as the result of a differential absorptive capacity by the rootstock, (2) by differential rates of translocation or (3) by a combination of both. The experimental studies reported herein are aimed at determining the relative importance of absorption by the roots and translocation by the stems as the main factor determining so-called rootstock influences.

That physiological functions do determine rootstock and scion relationships is evidenced by the recent work of Tukey and Brase (7, 8) who showed that reciprocal graft unions do not necessarily behave alike. For example, Northern Spy makes an excellent tree when used as a top scion, with Winesap as an intermediate stem piece, on a strong Crab rootstock; but when Winesap is the top scion, with Northern Spy as the intermediate stem piece, the resulting tree is poor and stunted. Thus, Northern Spy serves as a dwarfing agent to Winesap when it is used as an intermediate stem piece; Winesap, on the other hand, serves as a vigorous one to Northern Spy.

The present paper summarizes the results obtained from studies extending over a three year period. The work was started on Worcester Pearmain. In this variety the studies were confined to the branch and stem systems of the tree; they were subsequently extended to the variety Bramley's Seedling, and the scope of the work was widened so as to include a detailed examination of the entire root and top systems of a number of trees. During its progress Grubb (3), Rogers, Beakbane and Field (4) and Vyvyan (9), all working at East Malling, have published work dealing with the importance and influence of the intermediate stem piece in double worked trees.

The results presented here show that the so-called rootstock influence may be obtained by double-working and suggest that the effect is in a large measure produced by the stem part of the rootstock as distinct from its absorbing root system.

EXPERIMENTAL MATERIAL AND METHODS.

With the object of examining the relative functional importance of the stem part of a rootstock as distinct from that of its roots, material was prepared during the period 1927-30,

* The paper embodies studies begun by the senior author in 1929 and continued under his direction by Mr. Sham Singh and Mr. Donald Blair while studying at Long Ashton for higher degrees in the University of Bristol. Mr. Singh was awarded the degree of Ph.D. and Mr. Blair that of M.Sc. for theses embodying the results of their investigations. The complete theses are available in the University of Bristol Library.

and experimental plots were laid out at Long Ashton Research Station during the winter of 1930-31. Two scion varieties, Worcester Pearmain and Bramley's Seedling, were worked in a number of different scion-stock combinations. The four root-systems chosen were those of some miscellaneous seedlings and of the three clonal rootstocks, Malling Nos. IX, II and XIII. The reasons for this choice were as follows : Miscellaneous seedlings, in order to investigate the reputed variability of this class of rootstock; M. IX, because of its typical dwarfing influence ; M. II, as being the best known Paradise rootstock; and M. XIII, as being one of the more vigorous of the Paradise rootstocks. It should be added that a large body of practical and scientific information already exists concerning the growth and cropping of both of the scion varieties mentioned on the above rootstocks, and that this knowledge serves as a solid background against which to judge the results of the present series of investigations.

The three different methods of propagation adopted and the resulting build up of the trees were similar for both varieties and were as follows :

Method 1. Single-worked stem propagated trees.

The trees were produced by inserting the scion in the stem of the rootstock at a point a few inches above ground level. The procedure was as follows : In the winter of 1927, selected one-year transplanted rootstocks of the three Malling types IX, II and XIII and selected once-transplanted seedling Crab rootstocks were lined out in the usual manner. These rootstocks were budded during the summer of 1928. The trees made their first year's growth during the summer of 1929 and were headed at 2 ft. 6 in. high during the winter of 1929. At the end of the 1930 growing season they were normal two-year bush trees. It should be noted that this material was produced in the orthodox nursery manner ; but from the present point of view, it is emphasized that although the trees were single-worked, in the accepted use of this term, the scion was inserted in the *stem* part of the rootstock. In effect, therefore, a short length of about six inches of the stem of the rootstock remained interpolated between the scion and the absorbing root system.

Method 2. Double-worked stem propagated trees.

These trees were produced by inserting a 9 in. piece of a rootstock stem between the scion and its absorbing root system by the following method : one-year once-transplanted seedling Crab rootstocks were lined out in the nursery during the winter of 1927. Equal numbers of these rootstocks were then budded during the summer of 1928 with buds of M. IX, II, and XIII. The buds were allowed to make normal growth during the summer of 1929. In the spring of 1930 all the trees were grafted, half with scions of Worcester Pearmain, the other half with those of Bramley's Seedling. By this method 9 in. pieces of stem of the above three clonal rootstocks were left interpolated between the seedling rootstock and the scion variety.

Method 3. Bench grafted single-worked trees.

The essential feature of this method was that it eliminated all the stem of the rootstock. The procedure was as follows : Miscellaneous seedling Crab rootstocks were purchased through the ordinary trade channels. During February and March, 1929, all the lateral rootlets were removed leaving only the original tap root. The aerial or stem part of the seedling stock was then removed at a point well down on the root proper. The remaining root was then cut into pieces about 5 in. long. A good seedling provided two, or even three, such pieces. Working at a bench, scions of Worcester Pearmain and of Bramley's Seedling were then grafted on these root pieces, using the whip and tongue method. The graft unions were tied with raffia, and the completed tree units collected into bundles and placed in a cool, moist cellar in order to callus. They were planted out in April, 1929, at the normal nursery distances.

This method of propagation resulted in the production of trees in which all stem other than that of the scion was eliminated. When such trees were planted out in the orchard a portion

of the scion stem was, of course, below ground level, a point which should not be overlooked. The difference, therefore, between the stem-worked trees (Method 1) and the bench grafted trees (Method 3) was that the former had short lengths of the original rootstock stem remaining between the scion and the root system, whereas the latter had stems composed entirely of the scion variety.

The three different methods of propagation resulted in three different types of tree build up, and since in these studies comparisons are based on this material it is essential that these differences should be fully appreciated. In order to facilitate this a line drawing of each of the three resulting types of tree is presented in Fig. 1, Plate I.

The layout of the plots was that of randomized blocks, each block containing one tree of each rootstock/scion combination, thus allowing of statistical treatment of the results by analysis of variance.

Summary Tables only are given throughout this paper. The complete data are filed at Long Ashton and are available to workers who are interested.

TABLE I.

Showing the Mean data per tree for the complete range of rootstock and scion combinations. Variety: Worcester Pearmain. Data obtained 1933-34.

	Significant difference.	M. IX on Crab.	M. IX	M. II on Crab.	M. II	M. XIII on Crab.	M. XIII	Bench grafts.	Miscellaneous seedling.
Height (metres)	0·5	2·3	2·1	2·6	2·5	2·7	2·6	2·7	2·5
Spread (metres)	0·5	1·6	1·5	1·6	1·6	1·6	1·4	1·6	1·5
Head extent (sq. metres) ..	—	4·1	3·4	5·3	4·6	5·4	4·3	5·3	4·4
Girth (cm.)	2·1	15·3	15·0	18·4	18·6	18·9	17·0	18·5	17·8
Shoot growth :									
(*a*) Lateral leaders (cm.) ..	8·9	60·6	60·8	80·9	71·9	77·0	65·7	73·8	70·2
(*b*) Bourse leaders (cm.) ..	15·8	52·8	42·0	54·7	52·3	61·8	54·0	63·5	83·0
Precocity (Blossom trusses : number per metre) ..	1·9	6·2	7·4	2·7	3·1	2·0	2·7	2·6	2·9
Leaf area per unit length :									
(*a*) Lateral leaders (sq. cm.) ..	111	1,897	1,860	1,677	1,862	1,697	1,701	1,743	1,875
(*b*) Bourse leaders (sq. cm.) ..	237	1,558	1,665	1,207	1,334	1,294	1,465	1,257	1,287
Co-efficient of Variability : (%)									
(*a*) Girth		11·8	12·7	4·3	7·8	7·3	9·0	9·4	8·4
(*b*) Shoot growth		16·2	11·5	7·0	5·7	8·5	6·5	7·9	13·5

RESULTS.

WORCESTER PEARMAIN.

The data for this variety are given in summary form in Table I, and will now be discussed.

I. *Effect on tree size.*

The data show that there are no significant differences in height, spread, or head extent as the result of using the selected rootstocks either as complete root systems or as intermediate stem pieces. The effect on stem girth however, is more marked. Trees having M. IX either as a complete root system or as an intermediate stem piece possess significantly smaller stems than any other trees in the series. It is important to note that, in this respect, the two groups of M. IX trees behave alike and are clearly distinguished from all the rest.

II. *Effect on shoot growth.*

Other work at Long Ashton has been concerned with the relative value of the different kinds of one year old shoots. In fruit tree economy such shoots may have very different values,

so that in the present studies all the one year old shoots on a tree have been divided into categories based on their morphological origin. Thus, one year old shoots may be terminal leaders, lateral leaders, bourse leaders, first, second, or third sub-laterals, bourse shoots, and so on. Each of these shoots occupies a definite position and has its own value, either as tree building or productive material. In the present account only two categories of shoot are considered, viz. lateral leaders—i.e. the shoots arising from buds left in a terminal position by pruning away the rest of the shoot—and bourse leader shoots—i.e. shoots occupying a terminal position but developing from a bourse bud which had itself developed from a flower bud left in the terminal position by pruning.

The first important point to notice is that although both occupy a terminal position, the bourse leader shoots, as a class, are much shorter than the lateral leader shoots, except on trees on miscellaneous seedling rootstocks, where they are of almost equal length. The second point is that the lateral leader shoots of trees on M. IX and M. IX on Crab are significantly shorter than those of every other scion-stock combination except those on trees on M. XIII.

The data suggest that, as a rule, these two groups of shoots are different in character and that they are not affected to the same extent by rootstock and intermediate stem piece. In general, it is quite clear that the use of seedling roots as the absorbing root system has increased the extension growth of bourse leader shoots much more than that of lateral leaders. In fact the data now available show clearly that in any study of the effect of rootstock on tree vigour and cropping it is not sufficient to measure merely a mixed population of shoots. Any future study of this kind must recognize that the total shoot population must be classified, examined and compared in detail. This point will be further elaborated in a later section where it will be shown that each class of shoot has its own peculiar ratio of leaf area to unit length of shoot.

III. *Effect on blossom production and precocity.*

The influence of rootstock and of intermediate stem piece on precocity may be expressed either as the total number of blossom trusses produced per tree, or as the number of trusses produced per unit of length growth. The latter is the more satisfactory and has been adopted throughout this study.

A comparison of the data shows that the trees with intermediate stem pieces of M. IX, II, or XIII, respectively, have the same precocity as trees worked directly on these rootstocks. A further examination singles out the trees on M. IX along with those on M. IX on Crab as being highly precocious as compared with the remaining six stock-scion combinations. The figures are 7·4 and 6·2 blossom trusses per metre of shoot growth as compared with the nearest (i.e. the trees on M. II on Crab) with only 2·7 blossom trusses per metre.

It is therefore clearly established that as regards precocity the rootstock M. IX is outstanding, irrespective of whether it is used as a complete rootstock or as an intermediate stem piece. Furthermore, since there is no significant difference in precocity between the trees worked directly on the M. IX rootstock and those with intermediate stem pieces of M. IX but with vigorous absorbing root systems of miscellaneous seedling origin, there is unmistakable evidence that a typical rootstock effect—in this case an influence on precocity—has been produced by a rootstock when used as an intermediate stem piece and without the aid of the normal absorbing root system of this rootstock.

IV. *Effect on leaf area per unit of shoot growth.*

It is shown in Table I that irrespective of rootstock or intermediate stem piece, bourse leader shoots have a much smaller leaf area per unit of length than have the lateral leaders. Space does not permit of a discussion here of this important difference between these two classes of shoots on the same trees and often in close juxtaposition, but since in practice they are known to be of different value either as tree building or fruit forming units, the difference is an important observation.

The second point to notice is that the bourse leader shoots of trees on M. IX and M. IX on Crab have a much larger leaf area per unit length than have similar shoots on trees of every other scion-stock combination.

V. *Effect of rootstock on the Coefficient of Variability.*

The data collected during the course of this investigation provide an opportunity for a brief study of the effect of rootstock on size variability. The argument is frequently advanced that miscellaneous seedlings, when used as rootstocks, are the main cause of variable tree performance, i.e. differences in tree size, quality of fruit, yield of crop, etc. This argument is based on the assumption that because the rootstocks are genetically miscellaneous in origin and character, they will of necessity have varying effects on the growth of scions worked upon them. The use of clonal vegetatively propagated rootstocks is therefore advocated as the alternative, and it is suggested that the use of such rootstocks will result in greater uniformity of growth and cropping.

Since the investigation includes two groups each of twelve trees, worked on miscellaneous rootstocks, three groups of twelve trees worked on each of three different vegetatively raised rootstocks, and three groups of twelve trees each with different intermediate stem pieces but with absorbing root systems of miscellaneous seedling origin, ample scope is provided for the study of variability due to rootstock influence. There is, in fact, a direct comparison between trees on three vegetatively raised rootstocks and on miscellaneous seedlings, the latter used both in the normal and the bench grafting methods, and between both of these and the double-worked trees having root systems of miscellaneous seedling origin but uniform intermediate stem pieces.

At this point reference should again be made to the section on Materials and Methods in order that there should be no misunderstanding about the material that is being compared. The data presented in Table I deal with mean length per shoot, and mean girth per tree. These two measurements were chosen for this examination since they are unquestionably the most reliable indices of growth or vigour.

Reference to Table I shows that the variability throughout the whole of this material is remarkably small. Thus, over the complete range of rootstocks, which includes two groups of trees worked directly on miscellaneous seedlings, three groups double-worked on miscellaneous seedling Crab, and three groups worked on clonal rootstocks, the Coefficient of Variability for girth does not fall outside the range of 4·3 to 12·7 per cent. For shoot length per tree the variability lies within the range 5·7 to 16·2 per cent.

A comparison of the variability within the normal and double-worked trees shows that, as regards girth, the double-worked trees with intermediate stem pieces of IX, II and XIII, but with absorbing root systems of miscellaneous seedling origin, are *less* variable than are the trees worked directly on the corresponding clonal vegetatively raised rootstocks. The difference though small, except in M. II, is definitely in favour of the double-worked trees in every case. In mean length per shoot, however, the double-worked trees with intermediate stem pieces of M. II, IX and XIII are more variable than their opposite numbers worked directly on the vegetatively raised rootstocks. On balance, therefore, the double-worked trees are no more variable than the trees worked on clonal rootstocks, despite the fact that the double-worked trees possess absorbing root systems of miscellaneous seedling origin. Moreover, it is shown that, on the whole, the trees on miscellaneous seedlings are no more variable as regards either mean length per shoot or mean girth per tree than are the trees worked directly on clonal vegetatively propagated rootstocks, or double-worked on miscellaneous seedlings.

A further point of considerable interest is that the trees with M. IX, either as complete rootstock or as intermediate stem piece, constitute a much more variable group than do the trees of any other scion-stock combinations. This point will readily be appreciated by a glance at Table I and serves to indicate the peculiar character of this rootstock, and to strengthen

the idea that the trees with intermediate stem pieces of M. IX have the same kind of performance as those worked on this rootstock in the normal manner.

The relatively high degree of variability in shoot length for trees on M. IX on Crab deserves special mention. This is probably accounted for by the fact, mentioned earlier, that the bourse shoots on this scion-stock combination are much longer than the similar class of shoots on trees worked normally on M. IX. The variability in M. IX trees is undoubtedly due to this marked influence of scion-stock combination on the development of bourse bud shoots.

It is clear, considering that eight scion-stock combinations were involved in this experiment, and that five of them had root systems of miscellaneous seedling origin, that the variability factor is surprisingly small. It should be pointed out that the trees under consideration are still comparatively young and that differences between them may not as yet have had time to develop.

Bramley's Seedling.

A summary of the data for this variety is given in Table II. The comparisons are confined to trees with intermediate stem pieces of the three rootstocks M. IX, II and XIII. Any significant differences between the three groups of trees are therefore due entirely to the effect of the intermediate stem piece, since all other factors are constant.

Table II.

Showing the mean data for trees with intermediate stem pieces of M. IX, II and XIII. Variety Bramley's Seedling. Data obtained in 1934-35.

	Significant Difference.	M. IX on Crab.	M. II on Crab.	M. XIII on Crab.
Height (metres)	0·18	2·7	3·2	3·2
Spread (metres)	0·3	2·2	2·5	2·5
Head extent (sq. metres)	—	7·4	12·1	12·1
Girth (cm.)	1·8	18·3	20·9	22·2
Shoot Growth :				
(*a*) All shoots (cm.)	6·1	35·9	42·2	47·6
(*b*) Lateral leaders (cm.)	6·0	53·1	63·0	62·0
(*c*) Bourse leaders (cm.)	6·2	33·4	39·3	45·5
Precocity (Blossom trusses per metre)	0·9	2·6	0·4	0·4
Total tree weight (kilo.)	5·0	16·4	24·7	27·7
Total shoot weight (kilo.)	4·0	13·7	19·2	21·8
Total root weight (kilo.)	0·6	2·6	5·4	5·6
Root spread : Radius (cm.)	12·6	163·4	180·6	181·6
Root depth (cm.)	—	27·3	29·8	32·0
Top/root ratio (weight)	—	5·2	3·5	3·9
Dry matter of leaves (As % of fresh weight)	—	42·9	38·3	37·2
Leaf colour at defoliation	—	Bronze	Light green	Dark green

I. *Effect on tree size and character.*

The data show that, as regards height, spread, girth and head extent, trees with intermediate stem pieces of M. IX are significantly smaller than those with intermediate stem pieces of M. II or M. XIII. It should be noticed that there is no difference in size between the trees with intermediate stem pieces of M. II and XIII.

II. *Effect on precocity and flower bud formation.*

The data show that the trees with intermediate stem pieces of M. IX are highly precocious as compared with those in the other two groups. The figures are 2·6, 0·4 and 0·4 blossom

trusses per metre of shoot growth for M. IX, II and XIII intermediate stem pieces, respectively. A further point of interest is the marked spur flowering induced by the intermediate stem piece of M. IX.

III. *Effect on stem character.*

Certain characteristic features occur in the main stems of all these double-worked trees. A photograph of three typical stems of each scion-intermediate stem piece-rootstock combination is given in Fig. 2, Plate I. The following important points should be noted. In all trees of which M. IX is the intermediate stem piece, this piece forms an enlargement of the stems of which it forms a part. The point of greatest stem girth in such trees is at the upper union, i.e. where the scion joins the top of the M. IX intermediate stem piece. There is a marked upward and downward taper from this particular point on the stem. (Fig. 2, Plate I, right-hand three trees.)

In contrast to M. IX, the M. II intermediate stem pieces form a definitely constricted zone in the stem of which they form a part. The M. II part of such stems has made much less radial growth than either the Bramley scion or the stem of the rootstock—in this case seedling Crab. (Fig. 2, Plate I, centre three trees.)

The intermediate stem pieces of M. XIII merge easily and without change of diameter into the stem of the scion above and the stock below. The trees on M. XIII, in fact, show no visible evidence of having been double-worked and have the normal taper of a young apple tree. (Fig. 2, Plate I, left-hand three trees.)

It should be pointed out that the above stem features of these double-worked trees are constant throughout a large number of similarly constituted trees of both Worcester and Bramley, and in the field serve as a ready and reliable means of identification.

Space does not permit of an elaboration of these observations, but certain structural features of these unions should be noted here. The trees with intermediate stem pieces of both M. II and M. XIII are structurally strong. Notwithstanding the marked constriction of the M. II intermediate stem piece in the stems of which they form a part, the unions cannot be broken across except by the use of excessive force, and even then the break is of the normal elongated splintering type. M. IX is very different. The *upper* union, i.e. of the scion with the M. IX intermediate stem piece of these trees is invariably weak ; even moderate pressure will frequently cause such trees to break across at the union. This break is clean and the exposed ends present the appearance of a broken carrot rather than that of a piece of wood. In contrast to the upper unions of these trees the *lower* unions are strong. Only twice, with a large number of trees, has it been possible to cause a direct break at the lower union. It is interesting to reflect on the question : Why are the upper unions so weak and the lower unions so strong ? An answer to it might also supply one to some of the many problems connected with incompatibility and the lack of congeniality between certain scions and rootstocks.

IV. *Effect on root growth.*

The effect of the intermediate stem piece on root growth is even greater than it is on the top. The data show that trees with intermediate stem pieces of M. IX have made only half as much root growth as have the trees with intermediate stem pieces of M. II and XIII. As for top growth there is no difference between the trees with intermediate stem pieces of M. II and XIII. It would appear, therefore, that root growth is reduced more than top growth by an intermediate stem piece of M. IX.

V. *Effect on root range.*

Since the total weight of the root system has been reduced by one-half by using an intermediate stem piece of M. IX, it is not surprising that these trees should have a somewhat reduced

root range both as regards spread and depth. But this reduction is small in comparison with the large reduction in weight. The roots are reduced in diameter more than in length by the use of M. IX as an intermediate stem piece.

VI. *Effect on top/root ratio.*

The effect of intermediate stem pieces of M. IX is shown very clearly in the top/root ratios of the trees lifted for complete examination. Using total weight of top and total weight of root as the basis of calculation, it is seen that the trees with intermediate stem pieces of M. IX have a ratio of 5·2 as compared with 3·5 and 3·9 for M. II and M. XIII. Reference to the data shows that top growth of trees with intermediate stem pieces of M. IX has been reduced by about one-third and root growth by one-half, and that the marked increase in the top/root ratio of these trees is due mainly to the differential reduction in top and root growth.

VII. *Effect of intermediate stem piece on leaf characters and time of defoliation.*

During the early autumn of 1935 it was found that differences in the time of autumn defoliation were clearly evident between the three groups of trees. Fifty leaves were gathered at random on November 18th from each of the three groups of trees. A comparison of the data given in Table II shows that the leaves from trees with intermediate stem pieces of M. IX had an appreciably higher percentage dry weight than those from trees with intermediate stem pieces of M. II and M. XIII. The tough, leathery texture of the leaves on the trees with intermediate stem pieces of M. IX along with their slightly upturned margins marked them off very distinctly from the leaves on the other two series of trees. The whole appearance of these leaves was that of so-called high carbohydrate, or physiologically dry, leaves. By far the most outstanding difference between these trees was the time and the manner of their defoliation. The leaves on trees with intermediate stem pieces of M. IX showed autumn colouration as much as three weeks earlier than those of trees with intermediate stem pieces of M. II and M. XIII. The leaves from the trees with intermediate stem pieces of M. II and M. XIII fell without any appreciable change in colour, and they remained on the trees for at least 14 days after all those on M. IX had fallen. It should be stated, however, that strong winds prevailed at about this time and they undoubtedly accentuated the above difference. The differences in leaf colour, texture and time of fall were very marked and, like the swelling or constriction of the intermediate stem piece, served to distinguish certain trees.

DISCUSSION.

The question at issue is the location of rootstock influence. Is it a stem or a root function ? The evidence presented in this paper, covering a large number of trees and extending over a long period,* is conclusive on one point. The recognized characteristic effects of M. IX have been obtained without the aid of the root system of this rootstock. In the trees under consideration the absorbing root systems were of miscellaneous seedling origin. Similar material when used as direct rootstocks produced strong vigorous trees. The observed effects on growth and precocity were induced in the scion by the interpolation of a small piece of M. IX stem between the absorbing root system and the scion. It is argued, therefore, that the effects produced are largely determined by some function of the stem as distinct from that of the roots.

A second point is the similarity between trees produced by double-working and those produced normally. When nine-inch pieces of M. IX stem were interpolated between the scion and its absorbing root system the resulting tree could not be distinguished by numerical

* In 1944 a number of trees of similar constitution were still under observation and were showing the same general features as described above.

indices from trees of the same age worked directly on M. IX. Pomologists, however, notice a slightly more upright habit in the trees produced by double-working, and also a slightly different leaf poise.

The effect of an intermediate piece of M. IX stem is not confined to the above ground parts of the tree. Such trees have very much reduced root systems. Here again it is to be observed that these root systems, although of miscellaneous seedling origin, have a certain resemblance to the root system of M. IX. They have a relatively thick white cortex, and many of the roots have a kinked or wavy appearance.

Attention has been called (p. 53) to the importance of studying the effect of rootstock on the growth of one-year-old shoots. In previous studies along these lines (5 and 6) a mixed shoot population was used, but recent studies have shown that such shoots should be divided into groups or categories on the basis of their morphological origin. One-year-old shoots form the basis of all tree building material and in practice they are known to have wide differences in value depending on their origin and position. The present study has shown that bourse leader shoots have a leaf area per unit length very different from that of lateral leader shoots. Secondly, it is shown that seedling rootstocks tend to increase the mean length of bourse leader shoots and still further reduce their leaf area per unit length. From the present point of view too much emphasis cannot be placed upon this obvious refinement of experimental method. In future work on pruning, rootstocks, manuring, cultural treatment, etc., it will be essential to make detailed examinations of the effects of these factors not only on total growth, but on the relative distribution of growth amongst the various categories of one-year-old shoots.

The present study provides data relative to the problem of variability of scion growth due to rootstock. The trees on miscellaneous seedling rootstocks were no more variable than the trees on selected clonal rootstocks. It is recognized that the trees were still quite young when the study was made, so that differences may not have had time to develop.

Attention is directed to the growth and development of the rootstock stems when used as intermediate pieces. M. IX when used as an intermediate stem piece makes much more radial growth than either the rootstock or the scion, so that it becomes an enlargement in the stems of trees of which it forms a part. Development of the scion and rootstocks, however, is very much reduced as compared with other trees. M. II when used as an intermediate stem piece encourages a very rapid radial development of both the scion stem and the rootstock, but itself remains thinner than either, forming a waist in the tree. M. XIII makes the same radial development as the scion and the rootstock so that there is no evidence of double working in the trees. These observations permit of certain remarks concerning the vigour of rootstocks. Thus, the cross-sectional area of the intermediate stem pieces of M. II is less than that of M. XIII or M. IX, yet the M. IX trees are very much smaller and the M. XIII slightly larger. The intermediate stem pieces of M. IX have produced a marked dwarfing effect despite their large cross-sectional area. M. II is associated with a large and vigorous tree despite its relatively small cross-sectional area. It would appear that the observed effects on growth and cropping are not simple functions of cross-sectional area.

An important observation in this connection is the fact that in trees double-worked with M. IX the upper unions are very swollen and very weak, whereas the lower unions of the same trees are not swollen and are strong. It appears that most scion varieties fail to make good unions when grafted on M. IX, but that M. IX makes a tolerably good union when it is grafted on a series of miscellaneous seedlings. Although no explanation is possible at present, these observations are in line with those of Tukey and Brase (7, 8) and of Hodgson and Cameron (2). Tukey and Brase showed quite conclusively that certain scion–intermediate–stock combinations made perfectly good trees, whereas other trees made up of the same material but in a different order were useless. The idea was advanced that one scion produced a substance toxic to the other, so that when it was in the top position this substance caused the death of the intermediate.

The most recent work of Tukey and Brase (7) shows that even strains of apple may show uncongeniality distinct from the normal behaviour of the sort.

Hodgson and Cameron (2) working on some cases of scion dominance in Citrus suggest that when the vigour of the scion is less than that of the stock, it is the scion and not the stock that determines the total growth of the resulting tree.

The bearing of this view on studies in the physiology of rootstock and scion relationships is obvious. Double-working, both as a practical solution for certain problems of incompatibility and uncongeniality, and as an experimental practice is increasing rapidly. Recent developments in biochemistry and plant growth substances are providing an increasingly firm basis for an explanation of the observations recorded in this and similar papers. It seems clear, however, that for any future work along these lines the field of investigation has been narrowed down to functions of the stem as distinct from those of the root.

SUMMARY.

1. The object of the experiments was to determine whether rootstock influence depends on some function of the stem or of the root, or of both.

2. The trees used were designedly constructed by three different methods, using the two scions, Worcester Pearmain and Bramley's Seedling. They were built-up on miscellaneous seedlings, on three clonal rootstocks (Malling Nos. IX, II, XIII), and on miscellaneous seedlings with intermediate stem pieces of the three clonal rootstocks.

3. The trees with intermediate stem pieces of M. IX differed in almost every respect from those with intermediate stem pieces of M. II and M. XIII, but were similar to trees worked on M. IX in the normal manner.

4. The effect of the intermediate stem piece was more pronounced on root development than on top growth. Qualitative as well as quantitative effects were shown. The roots of trees with intermediate stem pieces of M. IX resembled in some ways the roots of M. IX.

5. The three interpolated rootstock stem pieces exhibited differences in their radial development. Those of M. IX had the same cross-sectional area as the intermediate stem pieces of M. II, yet the trees of the latter were twice as large as the former.

6. Certain characteristic differences such as leaf poise, general habit of branching and leaf colouration were shown by the trees with different intermediate stem pieces.

7. Where M. IX was the intermediate stem piece, the upper unions were enlarged and structurally weak, whereas the lower unions were not swollen and were structurally strong.

8. The physiological problems involved are complex. The accumulated evidence suggests that reciprocal graft unions do not necessarily behave alike. One variety may serve quite well as an intermediate stem piece to another, but the latter may not serve as a satisfactory intermediate stem piece to the former. The present work also shows that the chief practical advantages of the rootstocks M. IX, II and XIII can be obtained by a double-working method, using miscellaneous seedlings as the absorbing root systems. No trees have yet been produced by working direct on the roots of M. IX, II or XIII.

9. The present work focuses attention on the importance of the stem piece in rootstock and scion studies and makes a better understanding of normal apple tree physiology all the more urgent.

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PLATE I.

Fig. 1.

Single-worked. Double-worked. Bench grafted.

Fig. 2.

Stems of trees with intermediate stem pieces of M. XIII, II and IX; three trees each, left to right.

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THE PERSONAL FACTOR IN ROUTINE SPRAYING

I. A PRELIMINARY TRIAL ON APPLE SCAB

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THE results of spraying trials for Apple Scab control often show very erratic variation, which can mask real differences due to treatment. Incomplete spraying, especially of large trees, is a possible cause, for even a careful workman will sometimes leave a fairly large part of a branch unsprayed, so that variable results will accrue as between one tree and its better-sprayed, but otherwise similar, neighbours.

In 1943, therefore, it was decided to test the matter by comparing routine spraying, by an experienced farm hand, with specially thorough application, in which every branch was meticulously sprayed regardless of time, amount of spray used, or any other commercial factor. The experiment had been started in 1942, but not until the second post-blossom application. The inconclusive nature of the results was attributed to the cumulative influence of the earlier sprayings, which had been uniform for all trees within the limits of ordinary routine spraying.

It must be emphasized here, as will be evident from the Discussion (p. 65), that seasonal conditions, locality, and the circumstances in which the particular experiments are carried out, have an important bearing on the results of spraying investigations, more especially those of this nature. The results of this preliminary trial concern only one season, and in presenting them as part of a series, the writers are fully aware that further work under different seasonal conditions is necessary to enable these results to be appraised in their true perspective.

MATERIAL AND DESIGN.

Thirty trees were used in a plantation of large bush Bramley's Seedlings (average height approx. 15 ft.; spread 22 ft.) about 30 years old. They were arranged in six plots of five trees each, one half of the plots being sprayed normally by the farm hand and the other half with particular care by one of the writers. There were thus three randomized blocks of two treatments each, making it possible both to assess the variability between individual trees within plots receiving either treatment, and also to determine whether the more thorough spraying would reduce the total amount of Scab.

SPRAY PROGRAMME.

Sprays were applied at approximately 400 lb. pressure per sq. in. through three-nozzle lances delivering 3-4 gal. per minute. This modern type of wide, driving spray facilitated rapid, efficient spraying, and thus tended to diminish any difference between ordinary routine and specially thorough application. The routine spraying averaged about 4 gal. per tree and the special spraying some 6-7 gal.—a heavy rate for a fungicide on trees of this size. Economically, however, the rate is less important than the time taken, which was probably much more than doubled because of the special care taken to cover all the foliage thoroughly. The use of trigger valves on the lances made it possible to shut off the spray instantaneously, which kept down consumption. The applications were made at the following stages :

Green Cluster, on April 13th-15th, lime-sulphur, 2½ per cent. v./v.

Pink Bud, on April 20th, lime-sulphur, 1 per cent. v./v. Ascospores of Scab fungus not yet ripe and no infection seen. Spray weakened because of short interval between Green Cluster and Pink Bud, owing to rapid blossom development.

Petal Fall, on May 14th, for this early season more than a week late because of gales and rain. Lime-sulphur, 1 per cent. v./v. Ascospores had ripened in the interval—the first ripe ones were found on April 29th—and first infections were now apparent on the foliage.

Fruitlet, on June 3rd, lime-sulphur 0·5 per cent. v./v. and colloidal sulphur, 0·3 per cent. w./v. A spreader was added because Scab was by now well established, due probably to the delay in spraying at Petal Fall.

Insecticides were added as routine when necessary.

Secondary infection had favourable conditions for development two weeks or so after primary infection was seen, because a rainy spell followed from May 31st to June 7th. Subsequently, occasional moderate rainfall (June, 1·68 in.; July, 1·40 in.; Aug., 2·74 in.) sufficed for the slow progress of infection throughout the season, and it was not epidemic at any time.

RESULTS.

Experience has shown the desirability of discriminating between the proportionate number of individual leaves or fruits infected (*percentage infection*), and the degree to which they are infected (*mean area of infection*), for the one is not necessarily related to the other. The results are therefore considered separately under each heading.*

Percentage infection. Between June 7th and 11th, twenty new shoots were chosen at random from among the lower branches of each tree, and every leaf (about 10 on each shoot; 6,473 leaves in all) was examined for Scab.

Between September 23rd and 27th, fifty fruits were examined from each tree, the sample being drawn from the corners of the boxes into which the crop had been picked (Pearce, 1943). The results were expressed as percentage infection in each case, and they are set out in Table I.

TABLE I.

Percentage of leaves and fruits scabbed.

Spraying.	Leaves of lower branches.	Fruits.
Routine	9·1	25·6
Special	3·1	3·1
Sign. of difference ..	$P<0{\cdot}025$	$P<0{\cdot}025$

To estimate the level of significance, use was made of the angular transformation tabulated by Fisher and Yates (1938), because the original data are expressed as percentages. Advantage was taken also of the extended *F*-tables of Merrington and Thompson (1943). It will be seen that on the leaves examined in June before any appreciable secondary infection had occurred, the ratio of the two values was about 3 : 1, and that after secondary infection had had full play (i.e. on the fruit) the ratio rose to about 8 : 1, despite a known tendency for fruitlets scabbed early to drop as the season progresses.

To compare the chosen farm hand with his fellows, similar samples of leaves and fruits were drawn from other trees in the same plantation. Each of three other farm hands had been allotted a series of trees, which he sprayed throughout. The percentages of leaf infection for the

* When compounded, the two constitute *severity of infection*. The term "intensity" is frequently found in the literature, apparently with varying connotation. It has been avoided in this paper for that reason. According to the Concise Oxford Dictionary, "intensity" should be used only in a qualitative and not a quantitative sense (e.g. of depth of colour, of pain etc.)

three series were : 5·7, 6·1, and 7·1 ; and of fruit infection : 20·9, 29·1, and 38·8 respectively. These results do not lend themselves to statistical treatment because randomization was necessarily lacking, but clearly the performance of the chosen worker was at least average as regards fruit, though his results for leaves were relatively poor. The results shown by the three additional sprayers served to emphasize the increase in fruit infection over leaf infection, already well marked with the routine, as compared with the special, spraying.

Table II shows the standard errors representing tree-to-tree variability within plots of five. The angular transformation was again used. This Table shows also the expected standard errors calculated from the formula of Cochran (1938), giving the value for the variation between random samples drawn from a single population. Any excess of the actual values over these ideal ones is a measure of the extent to which the trees within a plot did not form such a single population, *i.e.*, of the variability between trees induced by differential spraying or other causes. The leaf records presented a difficulty in this connection for they were merely representative of twenty randomly selected shoots, and were themselves, therefore, not at random. Leaves on the same shoot, associated as they are, might well prove to be alike. The data at random for one leaf on each shoot were therefore chosen for analysis. This was done three times because each sub-sample was a small one. Each tree was thus represented by three sub-samples each of twenty leaves distributed very nearly at random.

TABLE II.

Variability between individual trees—standard errors of (transformed) percentage leaf and fruit infection.

Spraying.	Leaves on lower branches.				Fruits.
	Full sample.	Sub-samples : i.	ii.	iii.	
Routine	5·23	10·58*	8·46	9·79*	7·56*
Special	1·89	5·57	7·23	8·13	5·76*
Expected values ..	—		6·41		4·05

* Each of these values differs significantly (P=0·05) from its corresponding expected one.

The full sample showed that the routine sprayed trees were significantly more variable than the specially sprayed ones, and, according to two of the three sub-samples, more variable than would be expected by chance. On the other hand, the specially sprayed trees must have been nearly uniform, as none of the three sub-samples showed a standard error significantly greater than the expected one. The fruit records, however, showed no significant difference between treatments, though either value was significantly greater than the ideal one.

Bartlett (1936) has pointed out that, with a small sample, the distribution of the transformed variate is discontinuous ; the figures in Table II might therefore be partly explained by the resulting disturbance of variability.† From his diagram, however, it appears unlikely that this disturbance would invalidate the conclusions.

Mean Area of infection. The infected leaves were classified into those with : (1) less than and (2) more than one-eighth of the upper surface scabbed. The degree of infection proved unexpectedly low and the method adopted was therefore not very sensitive.

† If use is made of Bartlett's (1937) modified correction for discontinuity, the figures in Table II for variability (fruits) among specially sprayed trees becomes 4·58, which is just significantly less than 7·56, and not significantly more than 4·05.

Table III shows that there was a higher proportion of leaves in Grade (2), and in consequence a slightly higher Mean Grade, on the routine sprayed trees. The Binomial Theorem, however, revealed no significant differences.

TABLE III.

Number of scabbed leaves, classified according to mean area of infection per leaf.

Spraying.	Grades : (1)	(2)	Mean Grade.
Routine	231	7	1·03
Special	100	1	1·01

The infected fruits were classified into those with a total scabbed area of : (1) less than $\frac{1}{16}$ sq. in., (2) $\frac{1}{16}$ to $\frac{1}{4}$ sq. in., (3) more than $\frac{1}{4}$ sq. in. The method adopted was to view the fruit through a celluloid slide on which were drawn concentric circles of known radii, multiple infections being grouped by eye (Moore, 1930). The results are set out in Table IV.

TABLE IV.

Number of scabbed fruits, classified according to mean area of infection per fruit.

Spraying.	Grades : (1)	(2)	(3)	Mean Grade.
Routine ..	121	46	25	1·50
Special.. ..	13	8	2	1·52

Application of the χ^2-test failed to show any significant difference in the proportion of fruits in each grade as between treatments. Although this is the best available test, it is not ideal as it takes no account of the possibility that individual trees may behave differently, and because one of the expected frequencies (special spraying, grade (3)) was too low. There is thus no evidence that more careful spraying modified the mean area of infection on leaves or fruits.

The variability was not investigated in this instance ; a reliable estimate of mean area of infection per leaf or fruit for each tree was made difficult because few infected fruits were found on the specially sprayed ones.

DISCUSSION.

(*a*) *Percentage infection.* Ideally, very thorough spraying, accurately timed, should completely control Scab. That primary infection became established on the specially sprayed as well as the routine sprayed trees in this trial at about the end of the blossom period is attributed to the enforced delay in spraying at Petal Fall, a period that proved critical in 1943, particularly as the Pink Bud spray had been weakened from normal. It is common experience that a fungicide can prevent infection but cannot eradicate it without burning off the affected host tissue.

Leaf infection, recorded early in June, was a fairly accurate reflection of the extent of primary infection on the lower branches; for secondary infection, probably then incubating, had had little time to develop. The trees were evidently less well protected from primary infection by the routine than by the special spraying. Fruit infection, on the other hand, comprised primary and secondary infection for the whole season, and clearly the increment due to secondary infection on the routine sprayed trees was far greater than that on the specially

sprayed ones (Table I). There is a tendency in ordinary routine spraying for parts of branches, especially at the tops of large trees, to be missed or only inadequately covered by the spray, thus leaving unprotected sectors in which secondary infection can develop from any nearby primary foci already established, and from which it can later spread to other parts of the tree when the effectiveness of their protective covering has worn off. It was one of the particular objects of the special spraying to avoid this possibility, and evidently it succeeded, for the data show that the existing primary infections could have originated but little secondary infection, due doubtless to the efficient protection provided by the post-blossom sprays. Such meticulous spraying would not be economic in commercial practice because of the extra consumption of spray and, even more important, of time. The little extra *on an already high level of control* must be viewed in the light of what it costs to produce it ; in many circumstances it would doubtless be found unprofitable. Nevertheless, some middle course between very meticulous spraying and really careless spraying is clearly desirable, and would be highly profitable. Given adequate output of spray from the nozzles—a most important factor—the operator's skill in footwork and handling the lance to the best advantage is the best safeguard that trees, and most of all large ones, are adequately sprayed without waste of time or spray fluid.

As regards tree-to-tree variability in Scab infection, it is clear from Table II that, when judged by leaf records, the routine sprayed trees were more variable than would be expected by chance alone, but the specially sprayed ones were not. It follows that in some circumstances excessive variability in Apple Scab data may well be due to indifferent spraying. When judged by fruit records, the routine sprayed trees again showed more variability than would be expected from chance ; the specially sprayed trees, however, gave an intermediate result, and there is insufficient evidence to associate it with either the ideal value or that for the routine sprayed trees. The ultimate infection of the specially sprayed trees, being a function of an earlier, random, infection, would itself not be entirely at random. This could account for an increase in variability over the ideal.*

The effect of an increase in variability with the less thoroughly sprayed trees is to demand for statistical significance a greater difference as between the treatments in, say, a fungicide trial, than would be required from more carefully sprayed, and thus more uniform trees ; erratic variation can mask real differences due to treatment. (See Introduction.)

(*b*) *Mean area of infection per leaf or fruit.* The data are obtained solely from infected leaves and fruits. Thus where only one individual among one hundred is infected, the mean area of infection can equal that of ninety infected, though the percentage is 1 in one instance and 90 in the other.

Secondary infection, which multiplies upon a tree far more than it spreads from tree to tree, can be grouped into two main types :

(i) *Satellites* around primary infections, forming multiple infections on the same leaf or fruit. These increase the mean area of infection but have no influence on percentage.

(ii) *Migrants* on to other leaves and fruits, hitherto clean. These increase percentage infection but not necessarily mean area ; indeed, they tend to decrease the latter since they are usually smaller than primary infections.

Secondary infections can themselves become multiple through satellites (tertiaries, etc.), so in their turn increasing mean area. Primaries also can increase it where two or more develop on an individual leaf or fruit.

* Let x be the initial percentage infection, and y the final. If the relationship between them be such that :—

$$\frac{dy}{dx} > \sqrt{\frac{y\ (100-y)}{x\ (100-x)}},$$

then the standard error of y will be in excess of expectation.

Data concerning the degree to which individual leaves or fruits are infected can be interpreted in the light of seasonal conditions, even as the individual infections are themselves often a reflection of them. Thus, the summer drought at East Malling in 1934 inhibited the development of primary infections and virtually prevented secondary infection ; both mean area and percentage infected were therefore low. The 1930 season, fairly wet in May, became dry, and then wet again in August and September, when many fruits developed migrant infections, the spots remaining small because their period of growth was short ; mean area infected was again low, though percentage infected was relatively high. In 1931, weather conditions favoured infection ; there was heavy rain in April and average rainfall in May and June, followed by very wet weather in July and August. Multiple infections developed from an early date ; thus, both mean area and percentage infected were relatively high (Moore, 1936).

In 1943, the year of this trial, secondary infection began fairly soon after primary infection was seen, but drought, which began on June 8th and lasted virtually unbroken for five weeks, later checked it, and consequently there was little development of multiple infections. The difference between the two series of trees lay mostly in the greater proportion of migrants on the routine sprayed ones ; but since these were of much the same age and size as the primaries, it is not surprising that no difference in mean area of infection was found as between the two treatments. Nevertheless, under different seasonal conditions, the migrants might be much smaller than the primaries, with a consequent decrease of mean area infected on the routine sprayed trees. Again, under yet other conditions, conducive to satellite development, the routine sprayed trees might show a higher mean area figure than the specially sprayed ones if satellite development were greatly reduced by the special spraying and not by the routine.

CONCLUSIONS AND RECOMMENDATIONS.

1. *Thorough spraying lowered tree-to-tree variability in Scab control, and thus reduced experimental error.* In spraying experiments it is therefore worth the extra time and trouble involved. It must, however, be emphasized that the special spraying described here—designed solely as a " control ", or yardstick of comparison, and thus as an attempt to produce the ideal—probably goes too far even for spraying trials, where a high degree of accuracy is admittedly desirable. Moreover, there are trials of which the results are to have a direct application to practice, and in these the closest approximation to commercial spraying is desirable.

2. *Specially thorough spraying improved Scab control when compared with ordinary routine spraying.* In commercial practice, however, there is a limit beyond which thorough spraying would be uneconomic. Broadly, it can be defined thus : Where Scab control is unsatisfactory in spite of a sound programme of sprayings with a good fungicide, the spraying itself can be economically improved. Where, however, a high degree of control, though not complete, is already being economically obtained, the spraying is fulfilling its purpose and is better not tampered with, especially at the expense of time.

3. *Individual workers varied in the efficacy of their routine spraying.* This must be taken into account in experimental work, where error large enough to mask the results could be thus introduced. Where possible without incurring equally undesirable issues such as personal fatigue or failure to complete the work under reasonably uniform conditions, one person should do the spraying. Where more than one must be used, each should be assigned to some unit in the design, such as a block, row, or column.

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SUMMARY.

Specially thorough application of lime-sulphur for Apple Scab control, when compared with ordinary routine spraying:

(1) Reduced the tree-to-tree variability of percentage infection of leaves among the lower branches, and possibly also that of the fruits. High variability can therefore justly be attributed in some circumstances to indifferent spraying.

(2) Gave significantly better Scab control on leaves and fruits when infection was measured by *percentage*, but not by *mean area of infection per leaf or fruit*.

The routine spraying of different farm workers is compared, and some theoretical and practical bearings of the investigation are discussed.

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INFECTION OF OUTDOOR TOMATO CROPS BY *DIDYMELLA LYCOPERSICI*

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In August, 1941, while following up an advisory enquiry in the Evesham area regarding the occurrence of Stem and Fruit Rot (*Didymella Lycopersici* Kleb.) in a crop of outdoor tomatoes, evidence was obtained that infection had originated during the propagating stage, before planting out. Small's (1939) work in Jersey indicated that the most important source of infection of outdoor tomatoes with this disease lay in the propagating soil, contaminated either by infected plant debris or by spores liberated from pycnidia on infected seed. He considered that inoculum from one or other of these sources was carried to the field with the young plants, and these became infected at an older and more susceptible stage. The increased susceptibility of older plants has also been the subject of comment by Orth (1939) and Sheard (1943). Although Small demonstrated that the fungus could survive on plant debris in field soil from one season to another, he concluded that this source of infection was relatively less important. Infection from field soil developed late in the season unless the inoculum was actually in contact with the plants, a condition unlikely to occur following the removal of diseased stems and fruits and the ploughing of the soil.

The observations described below were made to confirm and extend already existing knowledge of the origin of Didymella infection in outdoor tomato crops and were collected over five seasons, from 1941 to 1945 inclusive, mainly in the Evesham area.

Although the acreage devoted to outdoor tomatoes in this area, as in others, has recently increased, a number of market gardeners have regularly grown this crop. Enquiry showed that Stem and Fruit Rot, locally known as Sleepy or Stalk disease, was of long standing, varying in intensity from year to year. Estimates of losses due to stem infection, based on five random samples of 100 plants, were made by the writer in August of each year from 1941 to 1944. In 1941, few crops were free from the disease but only in two did stem infection reach disturbing proportions, averaging 10 per cent. In 1942, heavy losses were more common. In 7 of the 22 crops examined, stem infection varied between 10 per cent. and 34 per cent., while in the remainder, wilted plants averaged about 1 per cent. Most of the 1943 counts varied between 1 and 5 per cent., with two records of 20 per cent. infection. The year 1944 was outstanding for the very early appearance of Stem Rot. Wilted plants were collected in the latter half of June, approximately a month or less after planting, and other outbreaks were seen early in July. Losses of from 10 to 15 per cent. were recorded on three occasions in mid-August, and in a crop visited on September 1st, 26 per cent. of the plants had wilted through stem infection.

The significance of these losses lies in the fact that fruit picking does not normally start until the beginning of August. Much of the fruit on a plant wilted by the middle of August is still undeveloped and is therefore lost. The number of plants so affected gradually increases and, in addition, losses of fruit by direct infection at the calyx end may be very severe in the latter half of the season. Evidence of the importance of this second phase of the disease is provided by the diseased fruit so often seen lying about the plant rows and removed from glasshouses used for ripening.

In 1941 and 1942, Stem Rot occurred on widely separated holdings amongst plants distributed from one particular nursery, in which the disease was identified in both seasons, suggesting that infection had originated in the propagating soil. Experiments were therefore

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planned to examine this suggestion and to explore the possibility of seed borne infection. At the same time, other experiments were designed to examine the viability of the fungus out of doors, in field soil, and to provide evidence of the importance of the canes used to support the plants, as a source of infection.

1. Seed infection.

Much of the tomato seed used in the Evesham area is saved by the growers themselves from outdoor plants, and samples of the 1942 crop collected from ten growers were examined in the autumn and winter of 1942. One hundred seeds of each sample were placed on moist filter paper in sterile Petri dishes, 20 seeds to a dish. After three weeks at laboratory temperature, pycnidia had developed, either on the seed coat or on a diseased portion of the hypocotyl just below the cotyledons, in 7 of the 10 samples. Single spore cultures of these fungi were made, and in the summer of 1943 typical representatives of them were compared with single spore isolations from naturally infected material as regards (1) their pathogenicity towards healthy outdoor tomato plants and to tomato fruits, (2) their pycnidial and spore characters, and (3) their growth in culture. On the basis of these observations, the pycnidial fungi isolated from the 7 samples of seed, were separated into three groups. One group contained non-pathogenic forms, possessing small, unicellular spores and identified as species of Phoma. The second group comprised forms apparently related to *D. Lycopersici* but with consistent morphological differences, and exhibiting only weak pathogenicity towards tomato stems. The fungi of the third group, isolated from 4 seed samples, were strongly pathogenic and produced typical lesions on tomato stems and on fruits. In morphological characters these fungi were identical with the cultures of *D. Lycopersici* and were identified as belonging to this species. Thus, *D. Lycopersici* was identified in 4 of the 7 seed samples which yielded pycnidial fungi after incubation. The percentage seed infection by Didymella could not accurately be determined under the conditions of this test, for the fungus may have spread from one seedling to another in the Petri dishes. Nevertheless, in each of the four samples proved to carry the fungus, at least 1 per cent. infection must have been present.

In 1944, an experiment was carried out to examine the relation of seed infection to outbreaks of the disease. Plants were propagated in sterilized soil from two stocks of seed. One of these, saved from diseased fruits, showed 70 per cent. infection. The other was prepared by mixing seeds of this heavily infected stock with seeds of an uninfected stock to give a sample containing 2 per cent. by number of seeds of the badly infected sample. The respective germination figures of the two samples in sterilized soil in the greenhouse were 69 and 88 per cent. During propagation, the plants of the two series were kept apart and no evidence of Didymella infection was observed during this period. On June 1st 250 plants of each series were planted out of doors in adjoining beds on land that had never before borne tomatoes.

The season was characterized by the exceptionally early appearance of Stem Rot. In this particular experiment a few wilting plants were collected on June 14th, a fortnight after planting out, and from then onwards infected plants were removed at intervals. Those plants collected in June were infected in the hypocotyl, at the upper limit of the primary root system developed during propagation, and located 1-2 inches below the soil surface after planting out. Thus, these plants were virtually deprived of their primary root system, and adventitious root development above the infected zone had not progressed far enough to support the plants' activities. Plants wilting later, in early July, showed a continuous zone of infection extending from the base of the hypocotyl to the base of the stem, just above soil level and involving the region from which new adventitious roots had meanwhile arisen, suggesting that infection had progressed upwards. It seems that an early attack, originating during the propagation stage, may be at first counterbalanced by new root development enabling the plant to survive until the end of July or beginning of August, by which time infection has passed upwards to soil

level, leading to wilting and death. This sequence of events is also suggested by Small's (1939) remarks that plants infected at a young stage before planting out, may form a new root system above the infected point and continue to grow for some time before ultimately wilting.

By August 24th, stem lesions were observed, which were considered to be of secondary or post-propagation origin, in contrast to the primary or propagation infection described above. These were at soil level, leaving the stem and hypocotyl regions below ground clean and healthy. The primary, basal type of infection was seen on several occasions in other places and it seems that it may be possible to distinguish primary lesions, resulting from propagation infection, from secondary lesions arising from spread in the field or from field soil. Further work obviously is needed to test this idea, but if true, it would prove a useful method of determining the source of infection.

In Table I is given the number of severely wilted plants, removed at different dates from the plots containing plants raised from lightly infected (A) and heavily infected (B) seed stocks respectively. Didymella infection was confirmed on every plant removed.

TABLE I.

Date.	Plot A.	Plot B.
21/6	6	4
29/6	—	3
12/7	6	7
24/7	2	12
1/8	9	18
11/8	16	24
24/8	24 (+9 sec.)	17 (+24 sec.)
Total	63	85

Whereas the plants from the liftings up to August 11th showed lesions of the primary type, some of the stem lesions on the plants removed at the last inspection (August 28th) were, judging from their position, due to secondary attack. They were at soil level, the root-bearing zone below it being healthy. Nine such infections were counted in Plot A and 24 in Plot B. Leaving these plants out of consideration the figures show that nearly three months after planting out, approximately one quarter of the plants raised from the lightly infected seed stock and approximately one-third of those raised from the heavily infected seed stock had succumbed to the disease. This result is very surprising in view of the great difference in the amount of seed borne infection between the two samples ; it indicates that the presence of only a small number of infected seeds in a sample is likely to have a disastrous result under conditions favourable for the development of the disease.

2. INFECTION DURING PROPAGATION.

The possibility of infection being contracted during commercial propagation was examined in 1943 and in 1944 by arranging for a number of growers to raise 100 plants each from one and the same healthy seed stock under their own conditions, with their own plants. The experimental plants were then set out in adjoining plots on land that had never borne tomatoes and examined at intervals for the presence of Didymella infection. The nurseries chosen for this experiment were selected deliberately so as to include a range of plant hygiene standards, from excellent to bad, and at the latter end of the scale were those having a past history of field outbreaks of Stem Rot amongst their plants. Six growers co-operated in the experiment in 1943 and five in 1944. The results of the two experiments are summarized in Table II. The

nurseries at which the plants were propagated are indicated alphabetically, each letter referring to the same nursery in both experiments. The growers' own losses from Stem Rot are also included, although these are not strictly comparable with those in the experimental plots, the plants having been raised from different seed stocks and, after propagation, grown under widely different conditions.

TABLE II.

Losses due to infection during the course of propagation.

1943 *Experiment.*

Nurseries.	Cumulative % losses in experimental plots.			Growers' own % losses in mid-August (16/8-23/8)
	9/7	27/8	16/9	
A	0	0	0	0
B	0	0	0	0
C	0	0	0	5
D	1	1	1	5
E	1	4	4	4
F	1	1	4	1

1944 *Experiment.*

Nurseries.	Cumulative % losses in experimental plots						Growers' own % losses.
	19/6	27/6	26/7	10/8	17/8	7/9	
A	0	0	0	0	0	0	0
B	0	0	0	0	0	0	0
C	0	0	0	0	0	1	rare
D	1	2	3	7	9	12	8 by end July
E	0	0	0	0	0	2	rare

In the 1944 experiment all the plants from nursery D removed up to August 17th, showed stem infection of the primary type described earlier. Of the two plants removed on this date, one showed primary, the other secondary infection, and all the plants removed from this plot on September 7th, together with those from nurseries C and E showed infection of the latter type. It seemed therefore that some secondary spread of infection had occurred and no further records were taken. It is worth emphasizing that the early outbreak of the disease amongst the plants from nursery D coincided with a similarly early outbreak amongst the grower's own plants. Amongst the latter, affected plants were first seen on June 16th, showing primary infections, and 8 per cent. of the plants had succumbed by July 28th.

It is significant that no Stem Rot appeared in either experiment amongst plants from nurseries A and B where the plants were raised under good conditions as regards soil sterilization and general hygiene, and where there was no previous history of the disease. At nurseries C, D and E the plants were raised under relatively poor hygienic conditions by growers who had all previously experienced attacks of the disease.

3. INFECTION FROM SOIL IN THE FIELD.

Experiments to provide evidence of the relative importance of this possible source of infection were carried out in 1943 and in 1944. In 1943 plants were raised in pots of soil

collected from a field that had carried severely affected crops in the two preceding years. A considerable quantity of potential inoculum had been incorporated with this soil for, after cropping, the old diseased plants had been ploughed in each autumn. Some of the soil was sterilized and four series of plants in pots, 25 to each series, which differed only in the duration of exposure of the plants to infection, were ultimately set up. This was effected by varying the period spent in unsterilized soil. No trace of infection was observed during the seedling stage and only one plant, of the series which had been grown from seed to maturity in unsterilized soil, developed Stem Rot, the symptoms appearing early in August.

In 1944 the problem was approached in a different manner, by setting out healthy plants among the various existing crops in fields each of which had borne a badly diseased crop during one of the three preceding years. At each of the seven sites selected for this experiment, 100 vigorous plants, raised in sterilized soil, were, with one exception, planted in random rows of ten plants each at the beginning of June. New canes were used as supports to avoid any chance of infection from this source.

Table III and the notes following it summarize the relevant data for each site.

TABLE III.

Attacks due to infection from soil in the field.

Site	Date of previous diseased crop.	Disposal of infected plants.	1944 Cropping.	Test plants showing Stem Rot by Sept. 19th.
1 ..	1941	ploughed in	Tomatoes	0
2 ..	1942	,,	Runner Beans	0 (occasional fruit rot)
3 ..	1941 } 1942 }	,,	Tomatoes	2 (one fruit rot)
4 ..	1942	—	Sprouts	0 (occasional fruit rot)
5 ..	1942	removed	fallow	0
6 ..	1942	,,	Onions	0
7 ..	1943	,,	Sprouts	8 (occasional fruit rot)

NOTES.

Site 1. Infection amongst the tomato plants surrounding the experimental plants was rare.
Site 2. One infected fruit was collected on August 3rd and others later.
Site 3. Stem lesions were observed well above ground level on two test plants at this site on September 18th. These infections may have been due to inoculum from the soil or from surrounding plants and canes, but very few of the latter were attacked.
Site 4. Fruit rots observed at the end of the trial period.
Site 7. Two infected plants were removed on August 14th, another on August 31st and the remainder on September 19th. All 8 plants attacked on this site bore lesions of the secondary type, the root-bearing zone remaining healthy. A small proportion of fruit was diseased by September 19th.

It seems clear from these two experiments that given an adequate rotation and a reasonable standard of plant hygiene there is little danger of an early and serious outbreak of Stem Rot arising from inoculum in field soil. In the first experiment one plant alone became infected out of 25 raised entirely in soil, the natural potential infective capacity of which could hardly have been higher. In the second experiment the disease did not appear (or appeared only mildly and late) on several sites, following diseased crops, the remains of which had been removed or ploughed in two or three years previously. Only at one site, number 7, where the land had borne a badly diseased crop in 1943 did any appreciable amount of disease appear, and even here more than half the infections did not develop until late in the season.

4. Infection from contaminated canes.

The distribution of infection in a crop examined at the beginning of September, 1944, suggested that the supporting canes were the source of infection. Where old canes had been used, up to 40 per cent. (with an average of 26 per cent.) of the plants were infected, the majority showing lesions well above soil level, while in a smaller area of the crop, staked with new canes, there was less than 1 per cent. infection.

In 1945 an experiment confirmed that the old canes were acting as a source of infection. Three plots of 50 plants were planted out of doors, 15 feet apart, at the beginning of June. The plants of the first plot were staked with canes suspected of carrying infection in the crop referred to above. Stakes from the same source, but soaked before use for 48 hours in 5 per cent. formaldehyde solution, were used in the second plot, while in the third plot new canes were used.

On July 30th, two infected plants were removed from the first plot and others subsequently. Throughout the experiment diseased plants were removed as soon as symptoms were noticed, together with their supporting canes. By September 7th, 38 per cent. of the plants staked with the unsterilized canes had become infected, the majority of them above, the others at, soil level. No infection whatever was seen in the other plots.

Discussion.

Small's general conclusions about the comparative importance of propagation and field soil, respectively, as sources of infection by *D. Lycopersici* are supported by the experiments and observations described above. Infection contracted during the propagation period is more dangerous because of its relatively early start and effects, and also because of the chances of extensive distribution of inoculum in the crowded conditions associated with this period.

While seed infection has been demonstrated amongst samples used for the commercial propagation of tomatoes—an important finding—it is recognized that the information obtained on this aspect of the problem provides no clue to the extent to which infection of this type occurs generally, for relatively few seed samples, from one season's seed crops only, were examined and no samples from indoor crops were tested. The infection of seed saved by growers may be related to their ignorance of the fact that Stem Rot and Fruit Rot are caused by one and the same fungus, together with insufficient care in selecting fruit for seed saving purposes, evidence of which was readily obtained.

The experiments have shown that the viability of the fungus in field soil under natural conditions does not appear to be very great, and the risk of infection from this source under good horticultural practice must be small. An interesting question in this connection is in what form does the fungus survive—as mycelium or by spores in pycnidia or in perithecia? The last possibility has been demonstrated by the writer's recent discovery of the perfect stage of the fungus in this country (Hickman, 1944). Equally interesting is the method whereby the fungus survives on canes stored from one season to the next, another point on which information is scanty. The limited observations made by the writer have failed to demonstrate the presence of either perithecia or pycnidia on canes, and this would support the conclusion of Kordes (1933) that spores overwinter in cracks on the canes. Although only a single instance of infection from canes has been proved during the writer's investigations it emphasizes very strongly the danger of infection from this source. If a detailed investigation of this aspect of the problem could be made the writer has little doubt that many similar cases would be brought to light.

SUMMARY.

An account is given of field experiments and observations on the sources of infection by *Didymella Lycopersici* Kleb. in outdoor tomato crops, particular attention being paid to:

1. Seed-borne infection.
2. Infection during propagation.

3. Infection from soil in the field.
4. Infection from contaminated supporting canes.

The evidence obtained is considered to support the conclusion that infection contracted during propagation—from soil contaminated by spores liberated from seed-borne pycnidia, or from plant debris—is of greater importance in relation to outbreaks of Stem and Fruit Rot than infection originating from field soil, and demonstrates the potential importance of contaminated canes as a source of infection.

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The writer wishes to acknowledge with gratitude the help received from various quarters, without which the work could not have been accomplished. In particular, acknowledgment is due to the growers who co-operated in the experiments, and to Mr. L. F. Clift, Mr. E. G. Ing and Dr. H. E. Croxall, for assistance in carrying out experiments.

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IMPROVING THE FIELD PERFORMANCE OF STANDARD PROTECTIVE FUNGICIDES

I. THE PLACE OF SPREADERS* IN THE SPRAY PROGRAMME FOR APPLE TREES

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THE physical chemistry of surface-active materials has been investigated by numerous workers, some chiefly with a view to their horticultural uses, particularly for fruit-tree spraying.

In this country, the theory and practice of wetting and spreading have been studied in the laboratory by Woodman (1924) and by Martin, in whose textbook (1940) the subject is fully reviewed and documented. These and other studies have elucidated some of the basic principles underlying surface activity, and different wetters, spreaders, and stickers have been compared. The factors involved and the criteria used for assessing results are many and complex, and the bearing of some of these on horticultural practice is thus admittedly uncertain. New and inconstant factors have to be considered in the plantation.

From the practical point of view, any spreader must, above all else, improve the efficacy of the spray, safely and economically. Field investigators agree that spreaders improve the uniformity of spray coverage, but the need to use them with protective fungicides to enhance disease control has not been clearly established.

A closely related problem is that of applying protective fungicides and contact insecticides together in the same wash. Up to the time when the present experiments were begun (1932) it had been customary to apply contact insecticides (e.g. nicotine) in the most drenching form that current spray machinery would permit, together with a good spreader (e.g. soft soap), which lowered the surface tension of the spray and allowed it to flow over the tree and thoroughly wet the insect. Protective fungicides, on the other hand, were applied at fairly high concentrations as soft, misty sprays from a single nozzle with small disc-orifice. The spray-fluid was of relatively high surface tension, and this method of application provided high initial retention of spray in the form of droplets. These two forms of spray necessitated separate application, that for fungicides being tedious and slow. Research on pest- and disease-control was demanding more attention to spraying by fruit growers, and the annual spray programme was becoming increasingly difficult to carry out because of the time taken to apply the many separate sprays.

It was necessary, therefore, to find a means of satisfying the growers' need for more rapid spraying, and, in taking advantage of the improvements in the design of spray machinery then being developed, to reconcile the two different types of spraying. As matters stood, fungicides, to be incorporated with contact insecticides, had necessarily to be applied heavily and with a spreader. The danger was that heavier application of fungicides might result in severe spray damage. A further difficulty, later met by the introduction of new organic detergents and wetting agents, was that soft soap, the standard spreader for contact insecticides, was incompatible with lime-sulphur and Bordeaux mixture, the two standard protective fungicides.

It was at least possible that protective fungicides, at increased dilutions over those commonly used as a soft, misty spray, and with a spreader to make up in improved distribution what the fungicide lost in strength, could be safely and effectively applied with contact insecticides.

* The term is used in its popular, and not its strictly chemical, sense, and is intended in this paper to include " wetter and spreader " to avoid wearisome repetition. Notes on the composition of all the spreaders tested will be found in an appendix at the end.

Hence, two related problems, spray damage and Apple Scab control, were chosen for investigation, and comparisons were made as set out below.

EXPERIMENTS.

Series I (1932-34). Lime-sulphur and Colloidal Sulphur.

Lime-sulphur at normal "full strength"	I.	A soft, misty spray	Gelatin, then favoured as a spreader and sticker, was included.
	II.	A drenching spray	
	III.	A soft, misty spray as in I, but with no spreader and sticker.	
Lime-sulphur more diluted	IV.	A drenching spray as in II, but more diluted than that in I, II, and III, to obviate damage by the heavier application. Sulphite lye was included as spreader to compensate for the lower fungicide content by improving its distribution on foliage and fruit.	

Opportunity was taken also to compare lime-sulphur, applied post-blossom, with colloidal sulphur, a promising fungicide that could be applied heavily without scorching the leaves and causing fruit-drop. Its use enabled soap-solution to be tested as a spreader (Plot B, below).

Two-year-old apple trees of the varieties Worcester Pearmain, Edward VII, Allington Pippin, and Newton Wonder, on No. IX rootstock, had been planted in 1929 in seven 4 by 4 Latin squares on each of two neighbouring plots, one (A) with good, and the other (B) with poor soil, similar to the other but exhausted by previous use as a rootstock nursery. Two spray trials were arranged by dividing each plot into four equal sub-plots, and the treatments given are set out in Table I.

Table I.

Particulars of spreader trials, 1932-3.

Sub-plots.	Plot A. (a) Lime-sulphur pre-blossom. (b) Lime-sulphur post-blossom.			Plot B. (a) Lime-sulphur pre-blossom. (b) Colloidal sulphur post-blossom.		
	Strength.	Spreader.	Sprayed.	Strength.	Spreader.	Sprayed.
I	(a) 3·3% (v/v.) (b) 1·0%	Gelatin (0·1% v/v.)	Lightly.	(a) 3·3% (b) 0·5% (v/v.)	Gelatin (0·1%)	Heavily.
II	ditto.	ditto.	Heavily.	ditto.	(a) Gelatin (0·1%) (b) Soap-soln.	ditto.
III	ditto.	Nil.	Lightly.	ditto.	Nil.	ditto.
IV	(a) 2·5% (b) 0·75%	Sulphite lye (0·75% v/v.)	Heavily.	(a) 2·5% (b) 0·5%	Sulphite lye (0·75%)	ditto.

The soap-solution was made by the method described by Martin (1932); 46 grm. caustic soda and 150 ml. oleic acid per 10 gal.

Spray applications were made at the Pink Bud, Petal Fall, and Fruitlet (2-3 weeks after Petal Fall) stages from a hand-operated "Cascade" machine at a pressure of about 200 lb. per sq. in. The form of spray—soft* or drenching†—was governed by a finger-operated nut,

* A very soft, misty spray, which was permitted only to drift through the trees.
† A fairly straight, driving spray, which was applied until the leaves were drenched.

which regulated the depth of the swirl-chamber in the single nozzle, and was determined by the writer, who personally applied the sprays. A satisfactory means of uniformly applying a proportionate volume of liquid per tree in the plantation is not known, but the amount was fixed, within limits, by the quantity prepared for each sub-plot. Nicotine (0·05% v./v.), but not lead arsenate, was included in all treatments when necessary for Sawfly, aphides, and small caterpillars.

An attempt was made over two years, in collaboration with Dr. H. Martin, to assess the amounts of sulphur deposited on the leaves in the respective sub-plots. These trials had originally been designed as collaborative work, but, as a satisfactory method for the estimation of the sulphur residues could not be found, the chemical results were inconclusive, and this part of the investigation was therefore abandoned.

Results.—Most of the trees cropped irregularly in the first two years of the trial, and attention was therefore directed mainly to spray damage to the leaves. A category record of marginal leaf-scorch, made on all varieties on both plots following the Pink Bud lime-sulphur spray, showed the following results :

TABLE II.

Leaf Scorch in 1932-3.

Sprays.	Mean Leaf Scorch (max. 2·0) per tree.	
	1932.	1933.
LS g (l) ..	0·09	0·25
LS g (**h**) ..	**0·97**	**0·93**
LS nil (l) ..	0·11	0·25
LS nil (**h**) ..	**0·86**	**0·82**
*LS sl (**h**) ..	**0·28**	**0·64**

LS=lime-sulphur. g=gelatin. sl=sulphite lye. **h**=heavily. l=lightly.
* Lime-sulphur more diluted.

Heavy spraying caused more leaf-scorch than light spraying, Newton Wonder and Edward VII being, in general, most affected. Spray damage was reduced when the dilution and spreading capacity of the spray were together increased. The lightly scorched trees showed rather more damage in the hot, dry summer of 1933 than in 1932.

The Allington Pippin trees cropped fairly well, but irregularly, in 1933. A bulk record made on similarly treated trees showed the following results (Table III).

Light application reduced the control of both Scab and Sawfly, and the new method (AIV) proved superior to the old (AIII). Sulphite lye, though with more diluted lime-sulphur (which caused less fruit drop (AIV, picked fruits)), was superior to gelatin on both plots. Gelatin had proved deleterious in a former trial (Moore, 1934*a*). Goodwin, Martin, and Salmon (1930) showed that gelatin and saponin each give rise to acid decomposition products that reduce the toxicity of sulphur against Hop Powdery Mildew (*Sphaerotheca Humuli*), but that it can be restored by the addition of enough alkali.

Infection was lighter on Plot B than on Plot A, but the reduction must not be attributed to the fungicidal superiority of colloidal sulphur over lime-sulphur. Experience has shown that the tree-growth on the poor (B) soil was much harder, less vigorous, and less liable to Scab—possibly as a result of such poverty—than that on the good (A) soil.

For Sawfly, the addition of a spreader to colloidal sulphur with nicotine, heavily applied, was very advantageous.

In 1934 two slight modifications were made in the trial: (1) Plot AI was heavily instead of lightly sprayed, but the strength of the lime-sulphur was not reduced, and (2) Sulphonated Lorol, used at 0·1% w./v., replaced gelatin on Plot AII, the lime-sulphur being further diluted as for sulphite lye. Plot AIII, the only remaining lightly sprayed one, was retained to permit comparison of the old method of application with the new.

TABLE III.

Fruit-drop, Scab, and Sawfly in 1933.

Allington Pippin.

Plots and sub-plots.	Sprays.	Dropped fruitlets.†		Picked fruits.		Whole crop.
		Total.	% Scab.	Total.	Scab Equivalent.‡	% Sawfly.
A I	LS g (l)	142	23·9	59	5·9	25·4
II	LS g (**h**)	186	**10·8**	74	**5·1**	**16·5**
III	LS nil (l)	84	27·4	43	3·2	23·6
IV	*LS sl (**h**)	98	**1·0**	106	**1·3**	**10·8**
B I	LS, CS } g (**h**)	70	**8·6**	67	**2·8**	**1·5**
II	LS, CS } g (**h**) ss	155	**3·9**	88	**0·9**	**9·9**
III	LS, CS } nil (**h**) ..	129	**3·9**	82	**2·3**	**20·9**
IV	*LS, CS } sl (**h**)	211	**0·9**	131	**0·4**	**4·4**

Abbreviations as in Table II, with CS=colloidal sulphur, ss=soap-solution.
* Lime-sulphur more diluted.
† Gathered up and Scab-graded at intervals during the season.
‡ A single value for severity of attack. Unlike a percentage, it takes into account the aggregate area of infection spots. The method of grading and computing has already been fully described (Moore, 1930*a*). The value 10 represents moderate, 30 very severe infection.

As judged by inspection of the spray deposits, both wet and dry, soap-solution was superior to the other spreaders, though every spreader treatment left a much more diffuse and uniform dry deposit than did the no-spreader treatments.

Leaf-scorch was not severe and was, as hitherto, marginal and most prominent on trees heavily sprayed pre-blossom with full-strength lime-sulphur with or without gelatin, especially those on Plot A. Newton Wonder was most affected, while similarly sprayed Allington Pippin trees, together with the Newtons, suffered pronounced leaf-drop.

The trees, especially of Allington, set a good crop. The results, omitting those for Edward VII, which proved highly Scab-resistant, are assembled in Table IV.

Light application of spray without spreader (AIII) was inferior to heavier application with spreader, both as regards Scab and Sawfly (controlled by the nicotine at Petal Fall), though the infestation of the latter was very low. Further, on Plot B, with colloidal sulphur post-blossom, heavy application without spreader was similarly inferior to heavy application with spreader. Here, the further dilution of lime-sulphur pre-blossom appeared to handicap sulphite lye as regards Scab-control. There was no consistent evidence of this on Plot A, where there was little difference between the spreaders.

Scab-infection in 1934 occurred at least one week before the Pink Bud spray was applied, and was commonly found beneath the reflexed calyx-lobes (Moore and Montgomery, 1935*).

* This work included a trial of spreaders, and little difference in Scab- and Sawfly-control was found as between spreaders used with lime-sulphur and nicotine at Petal Fall.

Infection in advance of spraying is the probable reason for the marked success of spreaders and heavy application in 1934, for a more intimate contact with lesions already present would be achieved, especially where the delivery pressure is relatively low. Scab lesions cannot be eradicated, but their power to originate secondary infections can be curtailed by desiccation. Any deleterious effect of gelatin would probably be outweighed by its value as a distributor of fungicide in these circumstances.

TABLE IV.

Fruit-drop, Scab, and Sawfly in 1934.

Plots, sub-plots, and sprays.	Variety.		Dropped fruitlets.		Picked fruits.			Whole crop.
			Total.	% Scab.	Total.	Scab Equivalent.†	% crop picked.	% Sawfly.
	Worcester Pearmain	I..	378	6·1	52	1·2	12·1	0·7
		II..	547	6·6	127	0·6	18·8	2·5
		III..	260	22·7	100	4·2	27·8	5·0
		IV..	512	6·1	162	1·8	24·0	1·0
A I LS g (h) ..	Allington Pippin	I..	1,120	12·1	498	3·9	30·8	0·4
II *LS SL (h)..		II..	1,229	13·5	626	3·3	33·7	0·4
III LS nil (l) ..		III..	1,352	30·0	596	11·3	30·6	3·1
IV *LS sl (h) ..		IV..	1,684	10·7	734	7·6	30·4	0·2
	Newton Wonder	I..	240	17·5	28	3·0	10·5	0·0
		II..	605	7·3	31	8·7	4·9	0·5
		III..	367	25·9	108	7·5	22·7	2·5
		IV..	501	16·4	61	6·5	10·9	2·0
	Worcester Pearmain	I..	193	6·2	75	0·9	28·0	0·8
		II..	255	11·0	63	0·0	19·8	2·8
		III..	108	24·1	52	2·4	32·5	3·1
B I LS, CS g (h) ..		IV..	96	20·8	82	1·0	46·1	1·7
II LS g (h) .., CS ss ..	Allington Pippin	I..	352	8·5	227	4·4	39·2	0·2
		II..	279	9·7	173	3·9	38·3	0·2
III LS, CS nil (h)		III..	523	22·9	307	14·9	37·0	5·9
IV *LS, CS sl (h) ..		IV..	296	13·2	199	5·0	40·2	0·0
	Newton Wonder	I..	114	6·1	33	6·3	22·5	0·0
		II..	227	7·5	52	6·5	18·6	0·0
		III..	234	15·4	110	8·9	32·0	2·0
		IV..	148	8·8	70	8·5	32·1	0·0

Abbreviations as in Table II, with SL=Sulphonated Lorol.

* Lime-sulphur more diluted.

† See footnote to Table III.

The Scab Equivalents are in means per tree ; the totals and percentages are per treatment (seven trees).

Comparison of the crop figures on Plots A and B shows that even very diluted lime-sulphur (especially, by inference, when applied post-blossom) caused fruit-drop. This was particularly so on Newton Wonder, which was severely damaged except where the spraying was lightly done. Herein lies one reason for the increased attention paid to spray damage since the abandonment of the soft, misty application of lime-sulphur ; varieties that would tolerate a light application will not tolerate a heavy one, and are thus tending to pass out of commerce.

CONCLUSIONS (SERIES I).

(1) *Spray damage.*—Heavy application of lime-sulphur caused more spray damage than light, and fruit-drop on Allington was greater with the stronger than with the more diluted spray. Marginal leaf-scorch was decreased when both the dilution and the spreading capacity of the spray were increased. Newton Wonder suffered severe fruit-drop following heavy application in 1934.

(2) *Scab- and Sawfly-control.*—Heavy spraying proved superior to light spraying. Nicotine and very dilute lime-sulphur with spreader, heavily applied, proved superior to nicotine and "full-strength" lime-sulphur without spreader, lightly applied, especially, against Scab, where infection occurred before the first application. There was no evidence to show whether heavy application or the presence of spreader was alone responsible. A spreader was advantageous to nicotine and colloidal sulphur, which was heavily applied.

(3) *Spreaders.*—There was evidence that gelatin—primarily a sticker—reduced the fungicidal efficacy of lime-sulphur, and that colloidal sulphur with soap-solution caused fruit-drop on Worcester Pearmain and Newton Wonder. Apart from this, the spreaders differed little in general effect.

Series II (1935-6). Lime-sulphur.

To obtain a better comparison of lime-sulphur with and without spreader the trial on Plot A was re-planned, that on Plot B being abandoned. The fungicide was applied throughout on commercial standards, at 2½% v./v. pre- and 1% post-blossom, and the six spreaders compared were: gelatin (0·1% w./v.), sulphite lye (0·75% v./v.), Sulphonated Lorol (0·1% w./v.), Lethalate Standard Wetting Preparation (0·05% w./v.), Agral N (0·05% w./v.), and an experimental sample of Ester Salts* (0·1% w./v.). All these, except the last, were in commercial use. Lime-sulphur without spreader was the seventh treatment. Each of the four sub-plots already mentioned was a replicate, the treatments being randomized among every variety within each sub-plot. Sprays were applied by hand-power as before, but with two nozzles on the lance and two men pumping, so that a pressure of 300 lb. per sq. in. was maintained. All trees were heavily sprayed until drenched, a new trigger valve instantaneously cutting off the spray; large hessian screens were used to arrest drift. Nicotine (0·05% v./v.) was included in all sprays to control insects, especially, at Petal Fall, Sawfly. A few spare, but similar, trees on the plot were used as unsprayed controls, and others to test lime-sulphur with an experimental sample of Sodium B Sulphonates (0·75% v./v. of a 20% solution).

In 1935 severe frost ruined the crop, and Scab on the foliage was negligible. The only noteworthy observation was that trees sprayed with lime-sulphur alone were readily distinguishable by their patchy, conspicuous spray deposit. Another trial, on Cox's Orange Pippin, in the same year showed that the addition of Lethalate Standard Wetting Preparation to lime-sulphur did not enhance Scab-control (Moore and Montgomery, 1936).

In 1936 the trees cropped well. Although other spraying trials (Marsh, 1931; Moore, 1934*a*) had shown the importance of pre-blossom sprays, the first (Green Cluster) application was deliberately omitted in order to reproduce the 1934 conditions. Scab was thus already present on the leaves of some trees when the Pink Bud spray was applied on May 6th. The trees were sprayed also at the Petal Fall and Fruitlet stages.

Lime-sulphur with any one of the spreaders gave distinctly better cover than lime-sulphur alone. By mid-June, Newton Wonder trees showed slight leaf-drop from post-blossom applications; most of the rosette leaves had already dropped, as in 1934, following the Pink Bud spray. Lime-sulphur with either Sodium B Sulphonates or Ester Salts, and especially the former, caused severe leaf-drop on Allington Pippin, but not on Newton Wonder, Worcester

* A modified product is now marketed as Estol H.

Pearmain, or Edward VII. Unsprayed trees were severely scabbed and the fruitlets showed a liberal sprinkling of Sawfly damage.

When the fruit records were made in September, it was soon apparent that both Scab and Sawfly had been almost completely controlled by every treatment. There was no Scab on Edward VII and virtually none on Worcester Pearmain, though the average Scab Equivalent for two unsprayed trees of this variety was 39·1. Table V sets out the results shown by Allington Pippin and Newton Wonder ; but as there was no effective difference between any of the spreaders except Ester Salts and Sodium B Sulphonates, the means per tree (of four trees each) for the five first-named spreaders were averaged. To indicate the level of potential attack, the data for the unsprayed tree of each variety are included.

TABLE V.

Fruit-drop, Scab, and Sawfly in 1936.

Lime-sulphur with spreader :	Allington Pippin.					Newton Wonder.				
	Dropped fruitlets.	Picked fruits.			% Sawfly (Whole crop.)	Dropped fruitlets.	Picked fruits.			% Sawfly (Whole crop.)
		Total.	Scab‡ Equivalent.	% Picked.			Total.	Scab‡ Equivalent.	% Picked.	
Five spreaders,§ averaged	605	154	2·3	20·9	0·6	97	22	1·1	20·0	1·1
Nil	**604**	**161**	**2·1**	**24·0**	**0·3**	**79**	**16**	**0·8**	**16·9**	**2·0**
Ester Salts*	519	42	0·8	6·6	0·2	73	1	—	1·8	0·9
Unsprayed tree ..	845	204	74·4	19·4	11·9	50	51	47·8	50·5	9·9
Sodium B Sulphonates†	565	35	1·9	7·8	1·2	39	5	—	10·6	4·0

* Average of four trees,
† of two trees, of each variety.
‡ See footnote to Table III.
§ Gelatin, sulphite lye, Sulphonated Lorol, Lethalate Standard Wetting Preparation, and Agral N.

Although the Green Cluster spray had been omitted, Scab-control was clearly too complete to enable any differential effects of spreaders to be shown, and a spray programme giving only partial control would have been preferable. Green and Goldsworthy (1937) encountered the same difficulty and made a similar suggestion to meet it. Yet the chief object of this experiment was to determine whether improved spreading power would confer any advantage on lime-sulphur and nicotine in normal practice, and evidently there was no advantage. Steer and Thomas (1935), and Steer (in Moore and Montgomery, 1937) found that no advantage accrued from the use of a spreader with lime-sulphur and nicotine for Sawfly.

May, 1936, was unusually dry (total rainfall 0·44 in. ; 21-year average, 1·74 in.) and this undoubtedly helped in the desiccation of incipient Scab colonies. The heavier and more forcible spray applied in Series II, assisted by the dry weather, evidently compensated the spray without spreader for any lack of spreading ability. The implication, at least as far as lime-sulphur with nicotine is concerned, is that the merit of the new principle tested in Series I lay more in the heavy application of spray than in the presence of a spreader.

Lime-sulphur again caused heavy fruit-drop on Newton; Allington, too, suffered similarly, when the inevitable loss of crop on the unsprayed tree through Scab and Sawfly is allowed for. Ester Salts and Sodium B Sulphonates greatly increased this fruit-drop.

CONCLUSIONS (SERIES II).

(1) *Spray damage.*—The intolerance of Newton Wonder, and, to a less degree, of Allington Pippin, towards lime-sulphur heavily applied was confirmed.

(2) *Scab- and Sawfly-control.*—With the heavy spraying given, at the higher pressure, a spreader conferred no advantage on lime-sulphur and nicotine at the very high level of control attained by all treatments. The use of an adequate volume of spray at adequate pressure appears to be of greater importance than the presence of spreaders.

(3) *Spreaders.*—There was again little effective difference between most of these; but Ester Salts and Sodium B Sulphonates increased spray damage, and were thus undesirable.

Series III (1937 and 1944). Lime-sulphur and Colloidal sulphur.

1937.—The preceding trials had left some doubt as to the need for a spreader with lime-sulphur when a relatively large volume of it was applied at a fairly high pressure. To test the matter further on commercial lines, a large-scale demonstration trial was arranged in 1937 on a plot of 16-year-old Cox's Orange Pippin trees on various rootstocks, with Worcester Pearmain trees as pollinators in alternate rows. In order that Scab could develop to some extent, lime-sulphur was applied at 1% v./v. pre- as well as post-blossom.* The plot was divided into halves, Lethalate Standard Wetting Preparation (0·05% w./v.) being added on every occasion to the lime-sulphur on one half and not on the other. Four sprayings—at the Green Cluster, Pink Bud, Petal Fall, and Fruitlet stages—were given at 300-350 lb. pressure per sq. in. from a 4 h.p. machine. The type of spray was thus similar to that received by the heavily sprayed groups in Series I and II, though at higher pressure. Headland trees surrounding the plot were sprayed on each occasion with lime-sulphur at commercial strength, viz. $2\frac{1}{2}$% pre- and 1% post-blossom, with no spreader.

Lead arsenate paste (0·4% w./v.) was added to the pre-blossom sprays on all trees to control caterpillar, and nicotine (0·05% v./v.) at Petal Fall for Sawfly.

SPRAY DAMAGE.

Effect of pre-blossom sprays.—By early Petal Fall all the trees were showing spray damage. With the stronger lime-sulphur, the leaf margins were extensively blackened and upcurled; with the more dilute spray, the damage was negligible and confined to the leaf tips where a spreader was used, but was severe and of a different type in the absence of spreader, when large, dull-brown, scorched patches were scattered irregularly over the leaves, often just on one side of the midrib. While the marginal form was typical of lime-sulphur damage, the dull-brown patches were unusual, and were attributed to arsenical damage due to the combination of lead arsenate with *very dilute* lime-sulphur, which had been unevenly deposited. The presence of the spreader had confined the damage to the leaf tips because much of the liquid had flowed off, leaving at each tip a residual pool derived from the uniform but thin film of liquid covering the lamina. Subsequent investigation (Shaw, in Moore, Steer, and Shaw, 1939) showed that the amount of soluble arsenical constituent of the combined spray increases as the proportion of lime-sulphur to lead arsenate decreases.

The most severely damaged leaves, found at the lower ends of the branches where the trees had been over-sprayed, were already dropping. Worcesters, similarly sprayed, showed little damage. No Scab was seen on any of the trees up to mid-May.

Effect of post-blossom sprays.—Extensive leaf-drop and scorch was shown by the Cox's in the absence of spreader; where the spreader was included there was none. Worcester

* This had already been done in another trial in 1936 (Moore and Montgomery (1937)) when, with severe and early infection, a spreader did not improve lime-sulphur except where the Green Cluster spray was omitted, and direct fungicidal action was called into play.

again showed little damage. The influence of rootstock was clearly seen, Cox's being much more affected on Nos. XIII and XVI—large, leafy trees—than on Nos. I, III, V, and IX, while those on Nos. II and X were intermediate. Rootstock influence on spray damage has been noted before on the same trees (Moore, 1930*a*, 1934*a*) and on Bramley's Seedling trees sprayed with Bordeaux mixture (Moore, 1936).

By June 28th there was heavy fruit-drop all over the plot. This coincided with normal June-drop ; but many of the larger dropped fruitlets (which, when cut open, showed evidence of satisfactory pollination) were among dropped ones, and this is unusual with June-drop. Moreover, on a nearby plot, on which some of the Cox's present had not been lime-sulphur sprayed, it was evident that the sprayed trees suffered fruit-drop in excess of June-drop. The concurrence of prolonged hot, dry weather,* heavy fruit-set, and lime-sulphur spraying has frequently been observed to result in excessive June-drop, though proof that the three are integral factors is necessarily difficult to establish experimentally. If the remaining crop is adequate, no harm is done ; but where experience points the need, lime-sulphur is best avoided in June or further diluted to 0·75%, where the other factors are operative. Where Red Spider is troublesome, it would probably be safe to resume with 1% lime-sulphur after the trees had settled down again in July.

Table VI gives the results in means per tree as obtained from fruit records. For Scab Equivalent the picked crop was graded into Scab categories as hitherto. The infestation of Sawfly was slight, and was disregarded.

TABLE VI.

Scab, fruit-drop, and yield in 1937.

Cox's Orange Pippin.‡

Lime-sulphur (1%).	Scab Equivalent.*	% of picked fruit scabbed.	% of trees with Scab-free picked fruits.	% of dropped fruitlets scabbed.	Weight of crop, including windfalls (lb.)
With spreader (55 trees)† ..	1·4	2·3	26·1	4·8	31·3
Without spreader (56 trees)† ..	0·6	1·1	63·8	3·7	14·7

* See footnote to Table III.
† Headland trees were not included.
‡ All rootstocks together.

Scab.—Though infection was slight, lime-sulphur without spreader was consistently superior to lime-sulphur with spreader. Records made on the picked fruits of Worcester Pearmain showed the same tendency.

Fruit Drop.—The weight of the crop was halved in the absence of spreader. The percentage picked crop (by number) was similarly halved,† as shown by Table VII, where the results are set out according to rootstock.

Trees on every rootstock except IX and XVI showed a marked difference in favour of the spreader. The trees on IX were evidently able to tolerate the no-spreader treatment while the others were not, a tolerance possibly explainable on biochemical grounds. Trees on XVI

* The latter part of May and the first-half of June brought hot, dry weather. The second post-blossom spray was applied on June 11th.

† The crop was reduced in the absence of spreader in another trial already quoted on page 82 (Moore and Montgomery (1937)).

on this plot had never matured more than a low proportion of fruits initially set (Moore 1934 *a* and *b*), owing perhaps to their remaining for a long time in a juvenile stage, before established cropping. Trees on XIII showed the same tendency, and tree-to-tree variability with both rootstocks was consequently high.

Table VII.

Percentage No. of fruit picked, 1937, including windfalls.*

Cox's Orange Pippin.

Lime-sulphur (1%)	Rootstock No. I	II	III	V	IX	X	XIII	XVI	Mean.
With spreader ..	59·1	37·8	38·2	43·9	36·5	43·1	22·4	12·0	36·6
Without spreader ..	27·5	14·2	20·6	17·0	34·3	16·9	6·2	11·8	18·6

* Based on fruit set, computed from the total dropped fruitlets and picked fruits plus windfalls.

The results leave little doubt that the spreader protected the trees from fruit-drop, defoliation, and leaf-scorch, caused by lime-sulphur or its soluble arsenical derivatives, by ensuring increased mobility of the spray-fluid on the tree through lowered surface tension, so that increased run-off and therefore decreased spray retention resulted. In fact the outcome, fungicidally and phytotoxically, was similar to what would be achieved by reducing the strength of the fungicide. Grubb (1921) found that lime-sulphur with Saponex caused less fruit-drop on Worcester Pearmain and Allington Pippin than lime-sulphur alone. He suggested also that the spreader may have slightly reduced the effectiveness of lime-sulphur against Scab.

1944.—A similar trial was made on the same trees with a 40% colloidal sulphur preparation heavily applied at 300-350 lb. pressure per sq. in., at Green Cluster (0·8% w./v.), Pink Bud (0·8%), and Petal Fall (0·6%). The spreader used was Lethalate Wetting Preparation* at 0·05% w./v. Lead arsenate powder at 0·2% w./v. was included at Green Cluster for caterpillars, and nicotine at 0·05% v./v. at Petal Fall for Sawfly.

Severe frost in May ruined the crop, and a dry spring was not conducive to Scab, which remained slight throughout the season. No spray damage occurred.

Leaves on extension growths selected at random from among the lower branches in July were examined and Scab-graded. The light crop was similarly graded at picking. The results are shown in means per tree in Table VIII.

Table VIII.

Scab in 1944.

Cox's Orange Pippin.

Colloidal sulphur.	% Number scabbed. Leaves.	Fruits.
With spreader ..	0·6	0·3
Without spreader ..	1·6	0·7

Scab was well controlled by both treatments, but both leaves and fruits showed slightly less infection where a spreader was used.

* A wartime substitute for the Standard Preparation, and based on sulphated cetyl alcohol.

Conclusions (Series III).

(1) *Spray damage.*—Lime-sulphur and lead arsenate without spreader caused more leaf-scorch, defoliation, and fruit-drop than lime-sulphur and lead arsenate with spreader. The injury to foliage is attributed to arsenical derivatives of the combined spray because lime-sulphur was diluted to 1%. The spreader, by lowering surface tension, increased the drainage of spray-fluid from the trees, thus leaving a thinner though more uniform deposit. Colloidal sulphur caused no damage.

(2) *Scab-control.*—No benefit was derived from a spreader used with lime-sulphur—indeed, control was slightly less good where it was used than where it was omitted—but a slight increase in fungicidal value was observed when a spreader was used with colloidal sulphur.

Series IV (1937). Home-made Bordeaux mixture.

Treatments were randomized on some established Cox's Orange Pippin trees at the Research Station. Bordeaux mixture (2-3-100)* with Lethalate Standard Wetting Preparation at 0·05% w./v. as spreader, applied at Petal Fall and Fruitlet stages following lime-sulphur (2% v./v.) and lead arsenate paste (0·4% w./v.) applied at Green Cluster and Pink Bud stages, was compared with similar Bordeaux mixture without the spreader. Nicotine (0·05% v./v.) was used on all trees at Petal Fall for Sawfly. A 2 h.p. machine supplied the spray through twin nozzles at 300 lb. pressure per sq. in., and a hessian screen arrested spray drift. There were unsprayed controls and also trees sprayed with lime-sulphur and arsenate pre-blossom and not sprayed post-blossom. The Bordeaux with spreader frothed excessively and wetting was excellent.

Table IX.

Scab and russeting with Bordeaux mixture in 1937.

Cox's Orange Pippin.

Spray.	Scab Equivalent.*	Russet Equivalent.†
Bordeaux mixture :		
(*a*) with spreader	0·5	44·1
(*b*) without spreader ..	0·1	30·5
Unsprayed :		
(*c*) throughout	5·4	5·9‡
(*d*) post-blossom only ..	0·5	14·2

* See footnote to Table III.
† Computed similarly to the Scab Equivalent, the data being obtained by grading the fruits into russet categories.
‡ Natural russeting.

Spray damage.—Bordeaux mixture without spreader caused slight purple spotting of leaves, shown in a survey on June 7th. Bordeaux mixture with spreader, however, had by then caused severe leaf-scorch ; defoliation was beginning and became much worse later. On the trees treated without spreader the damage was never more than moderate, leaf-drop to some extent being added later to the spotting. *Scab* remained slight throughout the season as in the lime-sulphur trial of the same year, described above.

The results for fruit, of which there was a good crop, are shown as means per tree in Table IX. There were four trees per treatment.

* 2 lb. copper sulphate and 3 lb. hydrated lime per 100 gallons of spray.

The Bordeaux mixture applied post-blossom contributed little to Scab-control, for infection was virtually eliminated by the two pre-blossom lime-sulphur sprays (*d*). There is thus no evidence as to the influence of the spreader on fungicidal activity. The fruits were severely russeted, the blemish being greatly increased by the use of the spreader. It is of interest that the pre-blossom lime-sulphur sprays with lead arsenate caused moderate russeting (*d*), already noted also with lime-sulphur at 1% on Allington Pippin (Moore, 1937). Moreover, Bordeaux mixture (8-12-100) applied at Pink Bud caused severe russeting on Cox's (Moore, 1930*b*).

The crop, excluding a few rotting fruits, was quality-graded to National Mark standards by an independent observer,* with the results shown in Table X.

TABLE X.

Quality grades: Bordeaux mixture in 1937.

Cox's Orange Pippin.

Spray.	% of total crop in grades:			Total crop.
	Extra fancy.	Fancy.	Domestic.	
(*a*)	5·6	40·1	54·3	322
(*b*)	12·0	30·8	57·2	367
(*c*)	29·3	33·4	37·3	287
(*d*)	27·2	31·5	41·3	537

The low percentage of fruits in the Extra Fancy grade with treatments (*a*) and (*b*) was a direct result of the severe russeting caused by Bordeaux mixture, that with spreader (*a*) being the more severe. The presence of Scab on the unsprayed fruits (*c*) was offset by the moderate russeting caused by pre-blossom lime-sulphur and arsenate sprays (*d*). This treatment, however, yielded a much larger total crop from the four trees than any of the others. Bordeaux mixture evidently caused crop loss in (*a*) and (*b*), and Scab similarly in (*c*), probably by the dropping of very small fruitlets.

CONCLUSIONS (SERIES IV).

(1) *Spray damage.*—Bordeaux mixture (2-3-100) was unsafe on Cox's, causing leaf-scorch, defoliation, fruit russeting, and loss of crop. The damage was increased by a spreader.

(2) *Scab-control.*—Infection was slight, and no evidence was forthcoming of the effect of adding a spreader to the Bordeaux mixture.

DISCUSSION AND CONCLUSIONS.

Scab-control.—Heavy spraying proved much superior fungicidally to light spraying, but it caused more damage. Nevertheless, satisfactory Scab-control was maintained and spray damage was reduced when the concentration of lime-sulphur was decreased for heavier application. The inclusion of a spreader *in a protective lime-sulphur spray* did not compensate, by better distribution, for what the fungicide lost in strength. Fungicidal action at a distance, reducing as it does the need for the perfect cover provided by a good spreader, probably accounts in part for the effectiveness of lime-sulphur (Marsh, 1929; McCallan and Wilcoxon, 1931; Moore, 1933*b*). The only evidence obtained that the spreader improved matters was in the comparison with lime-sulphur lightly applied at low pressure, a method now virtually obsolete.

* The writer is indebted to Miss C. P. Field for this assistance.

In one experiment in which infection had occurred before spraying began, a spreader with lime-sulphur, heavily applied, improved the control. In this instance, however, direct fungicidal, as well as protective, action was involved, and this requires intimate contact between fungicide and the fungus already present. Even so, a later trial showed that the heavier application was more likely to have been responsible for the improvement than the spreader; nevertheless the inclusion of a spreader might be desirable *where Scab is already well established*.

One clear advantage of including a spreader with lime-sulphur was a reduction in spray damage, but as this was most likely due to reduction of the deposited spray by increased run-off, a similar end could be achieved at less cost by greater dilution of the spray and its application without spreader. With heavy spraying, especially from modern machines (i.e. delivering large volume at high pressure), greater dilution of lime-sulphur than was customary with a soft, misty spray is very necessary to avoid spray damage. Good Scab-control has been obtained where no more than 1% was used pre-blossom (Moore and Montgomery, 1937; Moore, 1938), but thorough spraying and very careful timing are necessary, and lead arsenate must not be added. Experience shows that, where spray damage is to be avoided, Scab-control is not seriously jeopardized when considerable latitude is allowed in the dilution, but not the timing, of lime-sulphur applied pre-blossom. The $2\frac{1}{2}$% at Green Cluster and 2% at Pink Bud, now recommended as standard dilutions, are, at least in south-eastern England, to be regarded as maxima, or current full strength; similarly with 1% post-blossom. Ample evidence has accumulated to show the need for further dilution of this spray to 0·75% in June, where fruit-drop is likely. The interval between applications should be shortened to not more than two weeks, so that protective cover is maintained.

With home-made Bordeaux mixture, the spreader tested increased spray damage, probably through increased penetration of the host tissues by soluble copper derivatives of the spray. Bordeaux mixture with or without spreader, however, proved unsafe on Cox's, even when diluted to 2-3-100; indeed, this spray caused damage even at 1-$1\frac{1}{2}$-100 on Allington Pippin and Worcester Pearmain in 1937 (Moore, 1938); and, with its known inability to control Red Spider, it is clearly not suitable for apples (more especially when heavily applied), least of all those of dessert varieties. If used very dilute and protectively on culinary varieties in special circumstances, a spreader should be unnecessary for Scab-control.

Colloidal sulphur was fungicidally improved by a spreader, even when the spray was heavily applied, though with high pressure the improvement was only slight in the presence of light Scab-infection. It is doubtful whether an addition to the cost of this spray, already more costly than lime-sulphur, is to be advised for protective treatment where high pressure is available and Scab-control is the sole consideration. There appears to be little fear of damage from colloidal sulphur alone, even when heavily applied. Some varieties, however, notably Stirling Castle and Lane's Prince Albert, are known to be specially susceptible in some districts, and on these even colloidal sulphur may prove harmful.

Sawfly-control.—Limited evidence suggested that a spreader may be necessary with nicotine and colloidal sulphur heavily applied at relatively low pressure at Petal Fall, but this was not so with nicotine and lime-sulphur, at least when heavily applied at higher pressure. Steer and Thomas (1935) obtained a like result with nicotine and lime-sulphur; nevertheless they considered it advisable to recommend a spreader for the Petal Fall spray, solely to accelerate wetting of the Sawfly eggs, thus saving time and spray fluid.

No evidence was obtained as regards nicotine with Bordeaux mixture, but in a former paper Moore (1938) pointed out the need for a spreader with nicotine and weak Bordeaux mixture at Petal Fall unless cotton-seed oil is included, when the spreader should be superfluous.

Combined sprays.—Clearly, nothing is to be lost by applying fungicides and contact insecticides together in the same spray with a good spreader. Where adequate pump capacity and high pressure are available, however, the inclusion of the spreader is not necessary but may in some cases be desirable. Any improvement in Scab-control and Sawfly-control thus

provided is likely to be slight, and the decision to use a spreader or not must be made by the grower himself, in the light of his own experience. The practice of using one, chiefly for Sawfly, with lime-sulphur and nicotine at Petal Fall, for instance, would have little, if any, adverse effect on Scab-control, and might even be beneficial if infection had already occurred by blossom-time.

That lime-sulphur itself exerts some influence in Sawfly-control has already been demonstrated (Moore, 1933*a*), and this may partly explain any difference between colloidal sulphur and lime-sulphur. Steer and Thomas (1935) were unable to confirm this, but their results were obtained with very dilute lime-sulphur (0·75%) not comparable with that used by Moore, who recognized that the weaker the lime-sulphur the less its effect, and claimed no effect of lime-sulphur at 0·67%, with gelatin, on Sawfly.

It is usual to include a spreader where capsid or aphis is troublesome, as thorough wetting of either pest is specially necessary.

Comparison of spreaders.—There was little difference between the majority of them.* A few—Ester Salts and Sodium B Sulphonates with lime-sulphur, and soap-solution with colloidal sulphur—caused damage, and gelatin reduced the fungicidal efficiency of lime-sulphur. Many of the new textile wetting agents are so effective as spreaders and so easily prepared, that soap, more troublesome to prepare and with its known limitations in compatibility, is superseded in current fruit-tree spraying.

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SUMMARY.

Spraying experiments on apple trees showed that a spreader was unnecessary with lime-sulphur and nicotine for Scab- and Sawfly-control, given accurate timing of applications and adequate volume and pressure of spray. A spreader reduced spray damage in one experiment, probably by reducing the deposit through increased drainage from the tree. Weak Bordeaux mixture (2-3-100) proved unsafe, and is not recommended for apples, especially dessert varieties ; the inclusion of a spreader increased spray damage. Colloidal sulphur was improved by a spreader, especially when applied at low pressure with nicotine for Sawfly, but soap should be avoided on account of possible spray damage.

Light application of sprays diminished Scab- and Sawfly-control, but caused less damage than heavy applications.

There was but little difference in the effectiveness of the various spreaders tested, though a few of them were undesirable as they caused spray damage.

APPENDIX.

The following notes indicate the chief active ingredients of the proprietary and other spreaders concerned in this work.

Sulphonated Lorol (powder)—sodium salts of mixed primary alcohol sulphates, mainly C_{12}.

Lethalate Standard Wetting Preparation (powder)—contains 75% commercial sodium lauryl sulphate, 20% alkali salts of di-isopropyl naphthalene sulphonic acids, and 5% natural gum.

* Kearns, Marsh, and Martin (1934) came to a similar conclusion from results based on Sawfly-control. Treatment without spreader was not included in their trials.

Agral N (powder)—a sodium alkylnaphthene sulphonate.

Ester Salts (powder)—sodium salts of mixed secondary alcohol sulphates, C_{13}-C_{18}.

Sodium B sulphonates (20% solution)—sodium salts of sulphonic acids obtained in the refining of petroleum oils.

Sulphite lye (viscous liquid)—a sulphonated derivative of the manufacture of cellulose from wood pulp by the sulphite process. Contains salts of lignosulphonic acids, and is not standardized (Martin, 1932).

Gelatin (in sheets or powdered)—a refined form as used in cooking, fairly readily soluble in cold water, very readily so on warming.

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COVER CROPS FOR FRUIT PLANTATIONS

II. ANNUAL COVER CROPS

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INTRODUCTION.

Part I of this series (Rogers and Raptopoulos, 1945) described experiments with certain short-term leys, which tended to check fruit tree growth while the perennial cover crops were growing but stimulated it when they were turned in. It was suggested that it might be possible to avoid this check by using annual instead of perennial cover crops, and mentioned that experiments with them were already in progress. The results with some of these are here described.

A general review of the literature concerning cover cropping in orchards (including annual cover crops) was given in Part I, and the valuable effects of organic matter on the physical and chemical condition of the soil were noted. The recent work of Rayner (1944) and others has also drawn attention to the favourable effect of organic matter, particularly on the development of mycorrhiza, and the part this may play in enabling conifers to absorb nutrients from certain poor soils.

In America and Canada, particularly, annual cover crops are widely advocated for and used in orchards, and many authors have pointed out their merits, not only as a source of available nutrients but also as a method of increasing water absorption and avoiding soil erosion and leaching (Murneek and Hilbard (1942), Palmer and van Haarlem (1944), Collison (1940), and others).

In England, the use of mustard, rape, crimson clover and tares as green manures for fruit trees has been described and recommended by Seabrook (1929) ; but the cultivation of such annual cover crops in commercial fruit plantations has so far been only sporadic and intermittent.

The present paper has three separate parts : I, A short review of English orchard conditions in relation to use of cover crops ; II, Characteristics and yields of various annual cover crops at East Malling ; and III, A detailed experimental study of effects of six annual cover crops on fruit trees and orchard soil.

I. ENGLISH ORCHARD CONDITIONS IN RELATION TO USE OF COVER CROPS.

An orchard cover crop must of course fit in with and tolerate the normal orchard operations such as spraying, pruning, picking, etc. In England, tar oil and dinitrocresol winter sprays are widely used, and these may severely damage seedlings. Further, most of the vegetatively propagated fruit trees are of bush form, on rootstocks of moderate vigour, and are spaced more closely than trees in American orchards. It is therefore often difficult to prepare a seed bed with a tractor when the branches are weighed down with fruit. Shade may also be fairly intense, and may even become a limiting factor.

Fig. 1 shows, in diagrammatic form, the normal English orchard operations through the year, and also normal soil moisture tension and temperature conditions as deduced from many years' records in plantations at East Malling. It will be seen that soil moisture is usually plentiful from mid-September to the end of April (rainfall exceeding water usage in this period) but that the soil steadily dries out from May onwards, because rainfall is then less than water usage by mature apple trees, though water in the top layers of soil may become replenished from time to time by summer rains (Rogers, 1937). Theoretical considerations thus suggest that an ideal cover crop, to provide a bulk of organic matter without seriously competing with

the trees for water and nutrients, would consist of a plant, or mixture of plants, which would grow in the autumn, winter and spring, when the demands of the trees are low, and this idea is supported by the results of recent work by Shaulis and Dunbar (1944) in Pennsylvania. In the lower part of the figure the normal sowing, growth and turning-in times of various crops

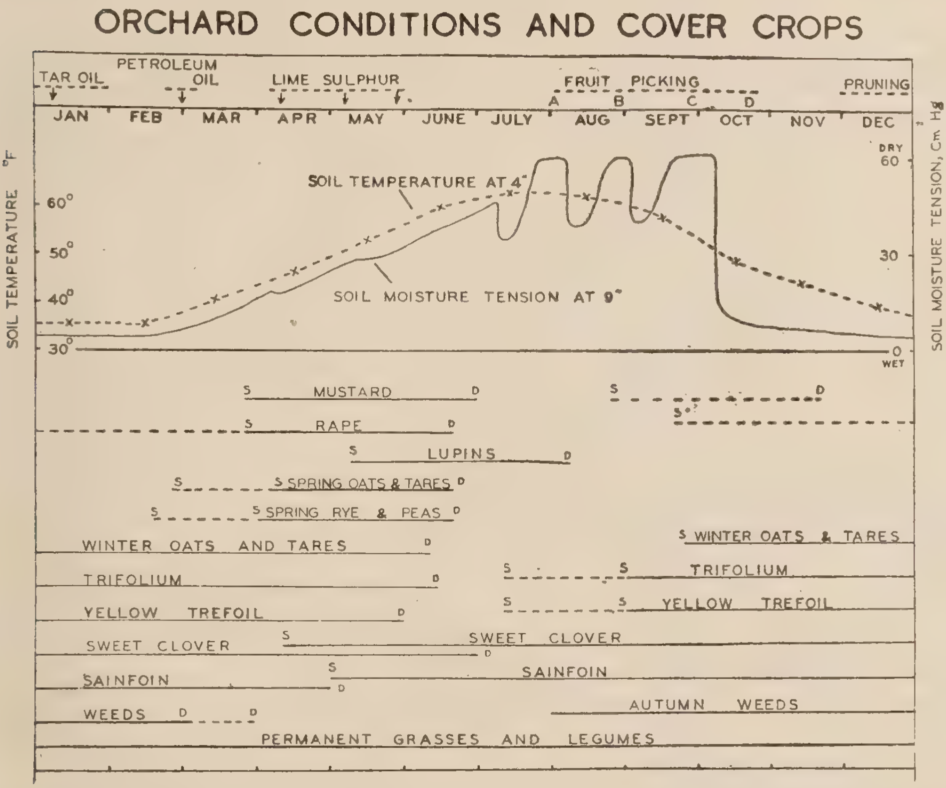

Fig. 1.

Diagram showing relation of time of sowing and discing-in of various cover crops to orchard operations, and normal soil temperature and moisture curves for the year.

S=sowing. D=discing-in. Broken lines indicate alternative periods.

Note.—Dinitrocresol is also applied in February-March, at a period similar to petroleum oil.

The fruit picking periods A to D correspond roughly with the varieties A, Beauty of Bath, B, Worcester Pearmain, C, Cox's Orange Pippin and D, Barnack Beauty.

and mixtures possibly suitable for English conditions are shown, and the characteristics and yields of these cover crops will now be considered.

II. Characteristics and yields of various cover crops.

Determinations of the yield of fresh and dry material from randomized samples of various green manures at East Malling from 1937 to 1941 showed that quite large variations occurred from plot to plot and from year to year. The sowing and sampling dates and the yields are shown in Table I, in which section A refers to strips within one plantation of dwarf apples where shade was but little, and section B to various plots, as specified, the figures being comparable only in so far as that they are all from crops in typical mature bush fruit plantations

on the same soil. It will be noted that all the green manure crops studied before 1940 were summer or early autumn ones.

TABLE I.

Yields of various cover crops at East Malling.

Orchard conditions.	Cover crop.	Date of sowing.	Date of sampling.	Yield tons per acre.* Fresh weight.	Yield tons per acre.* Dry weight.
A. In 18 ft. wide bays between rows of dwarf apples.	1939				
	Rape	June 15	Sept. 9	2·6	0·36
	Tares	,,	,,	6·0	1·10
	Mustard	,,	,,	6·2	1·84
	Fat Hen	,,	,,	7·2	1·68
	1940				
	Oats + Peas	May 7	Sept. 5	3·89	1·93
	Lupins (blue) ..	,,	,,	4·43	1·55
	1941				
	Mustard	April 23	June 25	3·51	—
	Tares	,,	July 9	3·10	—
	Lupins (Giant white)	May 28	Oct. 23	8·85	—
B.	1937				
Mature bush apples	Mustard	Aug. 1	Nov. 9	3·28	0·53
Young bush apples	Rape	,,	,,	8·48	0·96
Mature bush pears ..	Tares	,,	,,	6·34	1·00
,, ,, ,, ..	Nettles	Last cultivation. August	Nov. 15	5·92	1·51
Mature bush apples	Chickweed ..	,,	Nov. 18	5·98	0·95
	1940-41	(1940)	(1941)		
Mature bush apples	Crimson clover ..	Aug. 8	June 12	9·0	—
,, ,, ,, ..	Yellow trefoil ..	,,	,,	6·5	—
Mature bush pears ..	Oats + Tares ..	Oct. 29	June 6	7·70	0·87
,, ,, ,, ..	,, ,, ..	Oct. 9	,,	13·48	1·52

* Weights refer to tops only, except those of mustard and nettles in 1937 which included the roots, as pulled up by hand.

RAPE (*Brassica campestris* var. *napus*.) was very variable, giving from 2·6 to 8·48 tons of fresh material per acre (0·36 to 0·96 tons dry material). It may be used as an autumn, spring or summer cover crop and remains leafy and relatively succulent throughout its season. The amount of seed used is about 12 lb. per acre.

MUSTARD (*Sinapis alba*) gave 3·3 to 6·2 tons fresh material (0·35 to 1·84 tons dry material). This crop grows and matures quickly, and tends to get hard and woody soon after flowering. It is not winter-hardy, but both spring and summer crops are possible.

TARES (*Vicia sativa*) make a good cover crop usually smothering weeds and giving about 6 tons fresh, or 1 ton dry, material. Being a legume, this crop adds nitrogen to the soil. Its chief disadvantage is the high cost of seed. Formerly, 3 to 4 bushels (252-336 lb.) of seed per acre were sown ; now the cost is commonly reduced by mixing oats with tares, and two bushels of oats and one of tares (oats 84 lb. and tares 63 lb.) have proved satisfactory. Such mixtures, used as autumn or spring cover crops, have given as high yields as sowings of 4 bushels of tares alone. (See Fig. 2, Plate I.) Another mixture, oats and peas, as a summer crop, gave a fairly satisfactory yield in one season, but birds proved particularly troublesome with peas.

Lupins (*Lupinus spp.*). At Malling blue lupins (*L. augustifolius*) grew very poorly, probably owing to the high pH of the soil (over 7·0); but the giant white type (*L. albus*) grew vigorously, reaching 4 ft. in height and being rather a hindrance to fruit picking. About 150 lb. seed per acre was used. This is entirely a summer crop, sown about May, and may be particularly useful on acid soils.

Crimson clover or Trifolium (*Trifolium incarnatum*) gave excellent yields when sown in late summer and allowed to stand through the winter. (See Fig. 3, Plate I.) Twenty-four lb. of seed per acre was used. Both crimson clover and yellow trefoil, however, failed when sown too late in the autumn, especially when subjected to winter-wash sprays followed by cold weather. Part III of this series discusses the avoidance of this trouble and shows that by choice of times of sowing and of spraying damage can be much reduced. July and August seem the best sowing times.

Yellow trefoil (*Medicago lupulina*) though less vigorous than crimson clover also gave quite a good yield when it escaped spray damage. Twenty lb. of seed per acre was sown.

Weeds. Records were made of some spontaneous crops of weeds which were allowed to develop in various plantations. The fresh weight of fat hen (*Chenopodium album*), growing naturally, even slightly exceeded the 7·2 tons per acre given in Table I, which is for fat hen deliberately sown. Chickweed (*Stellaria media*) produced nearly 6 tons of fresh material in one summer, but it is usually killed by frost and by winter washes.

The annual stinging nettle (*Urtica urens*) gave a similar fresh weight, and a rather higher dry weight, but increased the difficulty of picking.

These figures show that certain annual weeds can provide a natural cover crop as heavy as sown crops in some cases. In others, however, experience shows that only sparse and poor crops are produced, and it is by no means certain what kind of crop will appear (Rogers and Raptopoulos, 1945). Further, most of the weed covers commonly occurring in orchards are not leguminous. Nevertheless, even in the absence of any experimental proof, growers have been quick to note the advantages of a cover crop which grows with no cost for seeding; and weeds from July onwards can now be seen in very many plantations which, in earlier times, were kept clean cultivated. In fact " clean cultivation with autumn weeds ", which Seabrook (1929) considered a new and even heretical idea, is probably now the commonest practice, and has been used as the basic control for some later trials.

Two other crops included in Fig. 1, viz. sweet clover (*Melilotus alba*) and sainfoin (*Onobrychis sativa*) are not strictly annuals. Giant sainfoin may be sown in April and disced-in a year later, or it may be left for two years. Common sainfoin is perennial. Both grow well on chalky soil, and can produce heavy crops under fruit trees. Sweet clover has as yet been little tried in England. It is normally a biennial, flowering in the year following sowing, but there is an annual form, called Hubam. The biennial form can grow to a height of 3 or 4 feet. The annual form *M. alba annua* was considerably less vigorous at East Malling and the same applies to *M. indica*, which is also an annual. Not enough data have yet been collected to judge the value of these crops for English conditions, but tests are being made. It should be noted that both sainfoin and sweet clover occupy the ground throughout the summer, and both are deep rooted. Permanent swards will be considered in a later paper.

III. Experimental trial of annual cover crops under apple trees.

Material and Methods.

This trial was carried out in a thirty-year-old commerical orchard of Barnack Beauty trees—a good late keeping dual purpose apple. The crops tested over three seasons, 1940-1943, were: winter oats plus winter tares, spring oats plus tares, rye plus peas, rape, and broad red clover, and they were compared with clean cultivation. A seventh crop, mustard, occupied

two spare strips in the plantation. Actually, crimson clover was used for the autumn-sown clover plots in 1940 and 1941, but for the re-sowing that became necessary in spring (discussed below), broad red clover was used. In 1942 broad red clover was used for both the autumn and spring sowing. Each of the main croppings occupied four replicated strips, 16 ft. wide and 120 ft. long, situated diagonally in the orchard and containing six experimental trees 17 ft. apart.

The seeds were broadcast and harrowed in during the autumn or spring (usually September and March) as specified above, and the resulting cover crops were disced-in in the early summer (May or June) by which time most of them had reached the flowering stage.

The four clean cultivated strips were kept free from weeds by cultivation during the spring and summer, but a few weeds were allowed to grow during late autumn and winter.

The same manurial treatment was given to all plots, including the clean cultivated ones, as follows: 1939-40, nil; 1940-41, 168 lb. sulphate of ammonia; 1941-42, 672 lb. meat and bone meal; 1942-43, 224 lb. sulphate of ammonia, and 1943-44, 336 lb. sulphate of ammonia, plus 2 cwt. flue dust (all per acre). Thus the amount of fertilizers given was on the low side.

The ordinary orchard routine was followed, including winter-washes each year. In 1941 and 1943 dinitrocresol wash (8 per cent.) was applied in February, and in 1942 tar oil wash (5 per cent.) in January. Careful observations were made of the effect of each operation on the cover crops.

The effects of the cover crops on the trees were studied by recording annual trunk girth measurements, weights of new wood cut off at pruning time, tree to tree observations on leaf colour, incidence of leaf scorches and time of defoliation, number and weight of fruits and visual observations on their colour.

Results.

The rate of seeding and the fresh and dry matter produced are shown in Table II. The seeding rates proved in general satisfactory, and gave a good stand of seedlings; but the rape and the clovers (both crimson and broad red) sown in autumn survived the winter sprays and weather so badly that each year it was decided to re-sow the plots in spring. As already mentioned, however, a separate study has now shown how this difficulty can largely be overcome. (See Part III, p. 103). Only the oats and tares survived the winter well, and even these did not remain unscathed.

Table II.

Kind and amount of seed used and weight of material produced.

Kind of seed.	Amount of seed lb. per acre.	Yield tons per acre. 1941. Fresh weight.	1941. Dry weight.	1942. Fresh weight.	1942. Dry weight.	1943. Fresh weight.	1943. Dry weight.	Total. Fresh weight.	Total. Dry weight.
Winter Oats + Winter Tares	84 / 63	9·81	1·21	2·82	0·45	9·38	1·90	22·01	3·56
Spring Oats + Spring Tares	84 / 63	2·51	0·58	4·30	0·67	8·65	1·45	15·46	2·70
Rye + Peas	120 / 60	3·68	0·61	2·48	0·40	6·38	0·97	12·54	1·98
Rape	24	3·40	0·79	1·86	0·21	7·05	0·90	12·31	1·90
Clover	24	5·41	0·74*	4·05	0·59	6·54	0·82	16·00	2·15
Clean cultivated	—	0·79	—	1·37	—	2·56	0·34	4·72	—

* Estimated from 1942-3 percentage determination.

1. *Weight of cover crops.*

The yield of fresh matter was determined from sample areas two yards square having one corner at a tree trunk, distributed at random on each replicate plot. All weights refer to tops only, cut 1 in. from the ground, just before discing-in. The weighed material was re-distributed over the respective areas after taking small samples for the determination of percentage of dry matter. Table II shows the rather large variation in yield from year to year of the various cover crops, reflecting their reaction to seasonal conditions and the orchard treatments. Over the whole three-year period, the greatest yield of fresh material was given by the winter oats plus winter tares (22·01 tons per acre), followed, though with a wide gap, by broad red clover and spring oats plus tares (16·00 and 15·46 tons). The contrast would have been even greater but for the severe damage caused to the winter oats plus tares by the tar oil wash applied to the trees in January, 1942, which, of course, the spring-sown crops escaped ; the dinitrocresol applied in February, 1941 and 1943 had a relatively less severe effect. None of the cover crops suffered appreciably from the routine lime-sulphur, lead arsenate or nicotine sprays employed.

In dry matter the crops of both winter and spring oats plus tares exceeded those of the clovers. The rape had the lowest yield. The mustard crops (not included in the Table) gave a total yield of 13·21 tons fresh material (2·09 tons dry) in the 3 years.

Thus, for weight and bulk of material, winter-sown oats plus tares was by far the most effective crop, but all the others also produced quite large yields. A few weeds allowed to grow on the cultivated plots in the autumn gave a small crop, 4·72 tons in the 3 years, and the extreme contrast between cover-cropped and cultivated is lessened to that extent.

2. *Tree leaf weight.*

One other source of organic matter on all plots, not so far considered, is the foliage of the trees themselves, shed each autumn. Little or no work seems to have been done on this, and no extensive data are available. The amount will obviously depend on the variety, size of tree, and the pruning method.

From data available at East Malling, derived from actual leaf weight determinations of two mature apple trees (Grenadier and James Grieve) it has been estimated that the dry weight of leaves returned to the soil is of the order of slightly less than half a ton per acre per year. If it is assumed that the leaf weight per unit of space occupied by the branches of the Barnack Beauty trees in the present trial is similar to that of the Grenadier, a computation taking into account the size and spacing of the Barnack Beauty trees shows that the dry weight of leaves returned to the soil by them would be of the order of two-thirds of a ton per acre. Naturally, such figures can be regarded only as rough approximations, and too much stress must not be placed on them.

3. *Soil organic matter.*

The soil in this experiment is a sandy loam, and was described in detail in a previous paper (Rogers, 1939). The orchard slopes gently to the north, but the soil is rather deeper towards its south end.

Soil samples were taken from each sub-plot, 9 months after the last cover crops had been disced-in, from depths of 0-6, 7-12, 13-18 and 19-24 inches. Each sample consisted of four borings. In a few cases the underlying ragstone rock was reached at depths of less than 24 in., so preventing the obtaining of the 19-24 in. samples at these points.

The organic matter (per cent. of air dry soil), as determined by Walkley's method, is given in Table III from which it can be seen that in general the organic matter of this orchard soil was rather low. This may be due to the continuous cultivation it had undergone in previous years and to its fairly high calcium content, resulting in increased decomposition of the organic matter.

TABLE III.

Percentage organic matter in air dry soil.

March 29th, 1944.

Depths.	Winter oats +tares.	Spring oats +tares.	Rye and peas.	Rape.	Clover.	Clean cultivated.
0 to 6 in. ..	2·948	2·563	2·697	2·915	2·797	2·529
7 to 12 in. ..	1·893	1·926	1·859	1·926	2·111	1·792
13 to 18 in. ..	1·323	1·139	1·340	1·223	1·474	1·256
19 to 24 in. ..	0·905	0·938	0·826	0·938	1·105	0·782
Total	7·069	6·566	6·722	7·002	7·487	6·359
Mean 0 to 12 in.	2·420	2·245	2·293	2·420	2·454	2·161
Sig. diff. P=0·05	0·180	—	—	—	—	—

The effect of some of the cover crops in increasing the soil organic matter over that of the clean cultivated strips was clearly evident in the top 12 inches ; at lower depths, as might be expected, the difference was slight. The plots with winter oats and tares, clover and rape gave significantly higher organic matter figures than the clean cultivated ones. All the other cover crop plots had more organic matter than the clean cultivated ones, but the differences are not significant. The winter oats plus tares and the rape added more organic matter to the top 6 in. than to the lower depths. Clover added substantial amounts of organic matter both to the top and to the second 6 in.

The average increase of dry organic matter for all cover crops, over the clean cultivated plots, amounted to 3·98 tons per acre for the top 12 in. (taking a cubic foot of soil to weigh 100 lb.). This is near the average three-year total yield of the cover crop tops only ; but the actual total organic matter produced includes an additional and probably almost similar amount for the weight of the roots and crowns (Rogers and Raptopoulos, 1945).

4. *Tree Growth.*

Girth increase.—Table IV shows the girth increases as a percentage of the previous year's girth of the trees under the various treatments, and this may be taken as a measure of rate of growth of the trees. The figures for 1940 (in which year the plots had uniform treatment, apart from the sowing of the first cover crops in September) show that there was initially great variation

TABLE IV.

Percentage girth increase of the trees in various cover crops.

Mean per tree.

Year.	Winter oats + tares.	Spring oats + tares.	Rye and peas.	Rape.	Clover.	Clean cultivated.	Sig. diff. (P=0·05)
Trial 1940 (started in autumn)	2·98	2·43	2·79	2·46	2·91	2·60	0·38
1941	3·08	2·42	2·74	2·52	2·66	2·60	Not sig.
1942	1·87	1·55	1·65	1·83	1·88	2·26	,,
1943 .. .. (ended in summer)	2·21	1·75	1·75	1·90	2·02	1·72	,,
Total	7·16	5·72	6·14	6·25	6·56	6·58	

among the trees. In spite of the fact that the figures are the means of four lots of six experimental trees, chosen at random, the trees destined for a winter oats plus tares cover crop actually had a significantly higher mean percentage girth increase in 1940 than those destined to have spring oats or rape. This cannot of course be due to the cover crop which was not sown until September, just as tree growth had stopped.

The growth rates in the three succeeding years during which the cover crops were grown and turned in each year show no significant differences. Attempts to lessen the variability by correcting the 1941-43 growth rates of each tree by their 1940 growth rate and by the 1940 trunk cross section failed to established significant correlations or any significant differences in the corrected mean girth increase percentages.

Weight of prunings (*new wood*).—With the short spur pruning method used, the weight of new shoots cut off is closely related to total new wood growth. The mean figures for new wood showed that, although there was great variation between treatments, none of the differences was significant.

These negative results, however, show at least that none of the cover crops significantly reduced tree growth in any year, a result in marked contrast to the severe check produced by the grass swards described in Part I. It was perhaps to be expected that no great stimulation of growth would appear in a period as short as 3 years, for Stokes *et al.* (1932), working with annual cover crops, reported that the cross sections of the trees varied very little during the four years of this experiment. Fagan *et al.* (1933) also reported that it takes several years before a cover crop will affect branch growth and circumference.

The fact that from 12 to 22 tons of organic matter were produced in three years by these annual cover crops under the trees without checking them suggests that such crops might be particularly useful under weak trees in relatively poor soil.

Leaf records.—Visual records of leaf colour were made in 1942 and 1943. In 1942 no marked differences were observed, but in 1943, following the heavy fruit crop of 1942, when slight nitrogen starvation symptoms appeared on most of the trees, the foliage of the trees over the clover cover crop was of a slightly darker green colour.

No leaf scorch of any importance appeared throughout the trial, although slight interveinal scorch was seen in 1942 and 1943 at the end of the growing season. There were no marked contrasts between the trees in the different plots.

5. *Yield of fruit.*

It was found that the trees were in a very biennial condition, and not all of them were in their " on " year at the same time. Therefore records for single years showed great variation between individual trees and between replicate plots. This doubtless also contributed to the variability in growth records, already discussed. Further, in 1941 and 1944 spring frosts reduced the crops to practically negligible amounts. The average figures each year for the various treatments, and also the four-year total 1941-44, covering two biennial periods, i.e. the three years when the cover crops were grown and one year's residual effect, are given in Table V. The last year's crop makes little difference to the total. Differences between the four-year totals are small and non-significant. However, a significant correlation was found between the fruit crop in the four-year period before the cover cropping started and the crop in the succeeding four years ; and when the latter was corrected by the former the error variance fell sharply from 1,562 to 278. The figures thus corrected by the method of co-variance and given at the bottom of Table V, show a mean of 281 lb. fruit per tree on all cover crops, and 251 lb. on clean cultivation. This difference, though not large, is significant. The corrected fruit yields on the various cover crop plots do not differ significantly amongst themselves, and it is evident that comparison for a longer period would be needed to establish such differences on these trees, if they exist.

Thus it is seen that cover cropping, with its addition of organic matter to the soil, resulted in a significantly better fruit yield than clean cultivation with a few autumn weeds.

TABLE V.

Weight of picked fruit per tree (lb.).

Year.	Winter oats +tares.	Spring oats +tares.	Rye +peas.	Rape.	Clover.	Clean cultivation.
1937-40 average ..	85	84	84	79	75	93
1941	15	10	21	24	9	13
1942	194	210	185	181	189	199
1943	71	42	64	57	76	62
1944	5	5	6	8	3	7
1941-4	285	268*	275*	270	277	280* lb.
1941-4 .. Corrected by 1937-40	280	267	274	281	301	251 lb.
			281			

* The apparent error results from the suppression of decimal places.

6. *Colour of fruit.*

Visual tree-to-tree records of fruit colour by well defined categories made in 1942 and 1943 and then tabulated showed that there was very little difference in colour between the fruit on the various cover crop plots and that on the clean cultivated ones. There was just an indication of more reddening on the cover crop plots than on the clean cultivated ones in both years, and, in 1942, a slightly yellower ground colour on the former. But the differences were very slight and did not approach those produced by grass swards.

DISCUSSION AND CONCLUSIONS.

The data given show that many annual cover crops can produce large amounts of organic matter under fruit trees ; but the yield of green and dry material may vary considerably under different orchard, soil and seasonal conditions.

Autumn- or spring-sown cover crops added significantly to the soil organic matter without causing any check to the growth of mature apple trees, and with advantage to their cropping power, even in so short a period as three years. It should be realized, however, that soil maintenance experiments of this type may need to be continued for a longer period before the full results become apparent. The effect of summer cover crops and of full crops of autumn weeds on tree growth and cropping still has to be tested. It has been shown that both of these types of cover crops can produce good yields of material, but the summer crops are likely to compete more severely with the trees than autumn or spring crops, both for water and nutrients.

Natural weeds, allowed to grow from about July onwards, and turned in during the winter or spring, are the cheapest type of cover crop ; but they are not so reliable as good sown cover crops. The best sown crops will produce several times as much material as weed crops, although the produce of weeds, such as fat hen and annual nettle, has sometimes exceeded that of the poorest sown cover crops. None of the main orchard weeds is leguminous, however, and the advantage of legumes as cover crops has appeared in many trials.

Pending full experimental evidence, it seems reasonable to conclude that autumn weeds will make a desirable minimum cover crop, where the trouble and expense of sowing a cover crop cannot be entertained ; but that suitable sown cover crops will maintain or build up the soil organic matter much better and more quickly than a crop of weeds.

Of the sown crops, winter oats plus winter tares, sown in September or early October, at about 84 lb. oats and 63 lb. tares per acre, have proved to be the most reliable. Their chief drawback is the relatively high cost of the seed. Broad red clover (24 lb. per acre) as a spring crop, and crimson clover (24 lb. per acre) sown in late summer have both given good results under favourable conditions ; but with these crops care is needed to ensure sowing at the best time, and to avoid damage from winter sprays.

Other cover crops, which are probably worth more attention but on which experimental results under fruit in England are not yet available, are lupins (on acid soils), sainfoin and sweet clover.

As with other cover crops, competition with the trees for nutrients and water must be carefully considered. A relatively generous manurial programme is probably very desirable, as this will help to avoid competition for water as well as nutrients. Experience suggests that in addition to any fertilizers which would be judged desirable for trees under clean cultivation, nitrogen, equivalent to about 168 lb. sulphate of ammonia per acre, should be applied to trees under cover crops while the cover crops are growing, and a further 168 lb. per acre when the cover crop is turned in. Phosphatic fertilizers are also desirable for leguminous cover crops.

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SUMMARY.

1. This paper gives : I, A review of English orchard conditions in relation to use of cover crops ; II, Characteristics and yields of various annual cover crops at East Malling ; and III, Detailed experimental results of three years' growth of six annual cover crops, on the soil and on the growth and the cropping of 30-year-old Barnack Beauty apple trees in replicated plots.

2. The relation of time of sowing and discing-in of various cover crops to orchard operations, soil temperature and moisture is discussed. Summer cover crops are more likely to compete with the trees than autumn and spring ones. Figures given include yields of tares (*Vicia sativa*), tares plus oats (*Avena sativa*), crimson clover (*Trifolium incarnatum*), yellow trefoil (*Medicago lupulina*), rape (*Brassica campestris* var. *napus*), nettles (*Urtica urens*), and chickweed (*Stellaria media*), as autumn or winter cover crops ; tares, tares plus oats, mustard (*Sinapis alba*), rape, rye (*Secale cereale*) plus peas (*Pisum sativum*), and broad red clover (*Trifolium pratense*), as spring crops, and lupins (*Lupinus* spp.), mustard, rape, tares and fat hen (*Chenopodium album*), as summer cover crops. Sweet clover (*Melilotus alba*) and sainfoin (*Onobrychis sativa*) are also discussed. All produced good yields under fruit trees, under some conditions, but yields varied greatly from plot to plot and year to year.

3. The cover crops whose effects were tested on apple trees for three years were (i) oats plus tares (winter) ; (ii) the same (spring) ; (iii) rye plus peas ; (iv) rape ; (v) broad red clover ; (vi) mustard, compared with clean cultivation. Highest yields of green matter were given by (i), followed by (v) and (ii). All caused increases in the percentage of organic matter in the 0-12 in. depth of soil, when compared with the clean cultivated plots, after three years. The increases caused by (i), (v) and (iv) were the largest and were significant.

4. All cover crops caused an increase in the fruit crop, amounting to an average of 12 per cent. This difference was significant. No significant differences in tree growth, either in

checking or stimulation, were shown by the trees over any of the cover crops, even after correcting the growth figures by co-variance with the previous performance of individual trees.

5. For East Malling conditions winter oats plus winter tares seems the most reliable cover crop at present fully tested. Broad red clover in spring has also given good results. Crimson clover is good, if precautions are taken to avoid winter damage, and mustard as a spring crop seems worth further trial. Several other crops, including sainfoin and annual sweet clover, are promising.

Certain weeds, including fat hen (*Chenopodium album*) and annual nettle (*Urtica urens*) can provide useful yields as autumn cover crops.

6. There seems little doubt that the use of suitable annual cover crops can add substantial amounts of organic matter to the soil in fruit plantations, and that these crops are less likely to cause a check to tree growth than either short-term leys or permanent swards.

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PLATE I.

FIG. 2.

A good crop of oats plus tares, being cut for sampling, in a plantation of dwarf apples. In commercial practice the crop can be disced straight in without preliminary cutting. Photograph taken May 18th, 1944. The measure is marked in feet.

FIG. 3.

Crimson clover (*Trifolium incarnatum*) being cut for sampling. May 18th, 1944.

COVER CROPS FOR FRUIT PLANTATIONS

III. TIME OF SOWING AND WINTER WASHING IN RELATION TO SPRAY DAMAGE TO ANNUAL COVER CROPS

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In Part II of this series (Rogers and Raptopoulos, 1945) it was pointed out that certain annual cover crops, especially those sown in autumn, may be greatly injured or even completely killed by routine orchard operations such as spraying. In the trials described, both rape and crimson clover, sown in autumn, were rendered useless in two or more seasons by tar oil or dinitrocresol winter washes, followed by cold periods; oats plus tares, also, though surviving in each year, were checked to some extent.

That the damage was not due to cold weather alone, was shown by the fact that cover crops protected by mats while the trees were being sprayed, grew normally, while the surrounding plants were checked or killed by the spray drift. In other orchards, too, not winter washed, the cover crops suffered no visible check. It also appeared that seedlings, well established when they were sprayed, were less badly injured than weaker ones. That winter washes should have a severe effect upon seedling plants was to be expected, for both dinitrocresol and, to some extent, tar oil, have actually been used as weed killers. (Robbins *et al*, 1942.) On the other hand, lime-sulphur, Bordeaux mixture, nicotine, and lead arsenate sprays, as applied to fruit trees, have not been found to damage cover crops to any appreciable extent.

Another factor to be considered in growing cover crops, especially annual ones, is the possibility of a toxic condition of the upper layers of soil arising from repeated spraying with various poisonous substances. This has been found to be a limiting factor for certain cover crops in the U.S.A. (Morris *et al*, 1939), but such effects have not yet been recorded in England.

The purpose of the present trials was to find out whether damage to certain orchard cover crops could be minimized by careful choice of times for sowing and for spraying. They also serve incidentally to show which times of spraying within the winter period have the greatest weed killing effect.

MATERIAL AND METHODS.

The cover crops tested were crimson clover (*Trifolium incarnatum*) and a mixture of winter oats and winter tares (*Avena sativa* and *Vicia sativa*). The trials were repeated in two successive seasons, 1942-43 and 1943-44. In the second season a further mixture, rye (*Secale cereale*) with tares was also included, since preliminary observations showed that rye is extremely resistant to tar oil and dinitrocresol damage.

Four sowing times for the crimson clover were tested, viz. July, August, September and October, and the last three for the oats and tares. Five separate spraying treatments and an unsprayed control were compared on the plants of each sowing date. The sprays represented various possible commercial treatments for orchards, viz. tar oil (a miscible tar oil wash at 5 per cent.) in December, in January and in February; dinitrocresol (dinitrocresol-petroleum oil wash at 8 per cent.) and petroleum oil (field mixed petroleum oil soap wash at 6 per cent.). Both the tar oil and dinitrocresol were commercial brands, as used on the Research Station plantations. The petroleum oil was J.D.2 spindle oil at 6 per cent., with 2 pints of oleic acid and 6 oz. caustic soda per 100 gallons of water. The dinitrocresol and petroleum oil were applied in February in 1943 and in March in 1944, corresponding with the times of application of these washes to the commercial plantations at the Research Station.

The experimental plots were placed well away from fruit trees, to avoid any interference from orchard spray drift. The treatments were replicated four times ; at each sowing four long strips, divided into randomized sub-plots, each 4 ft. by 5 ft., for the spraying treatments, were sown. Thus the crimson clover, having 4 sowing times and 6 spray treatments, had 96 sub-plots, and the oats plus tares, with 3 sowing times and 6 spray treatments, had 72 sub-plots.

The sprays were applied with a small hand-sprayer, at a standardized rate corresponding approximately to 250-300 gallons per acre. This fully wetted the plants. A wooden screen placed around each sub-plot during application of the spray confined it to the area concerned.

The amount of seed used was 24 lb. crimson clover, and 84 lb. of winter oats plus 63 lb. winter tares per acre. It was sown by hand in shallow drills and raked in. The operations of sowing and spraying were all carried out as nearly as possible in the middle of the months specified.

Small preliminary trials were also made in 1944 with a thiocyanate oil winter wash, as detailed later.

RESULTS

Crimson clover.

The July- and August-sown seed germinated well in both years. By December, when the first spray was applied, the July-sown plants were about 10 in. high and the August-sown ones 5 in. They had abundant leaves, and practically covered the ground. The strong growth of the July-sown plants was upset in both years, however, during the hot days of late summer, by clover rot (*Sclerotinia trifoliorum*) and by another fungus that caused rusty spots on the leaves and was identified as *Dothidella trifolii*. These attacks caused gaps in the plots, particularly in 1942, and resulted in a lower yield from the July-sown plants than from the August-sown ones in that year.

The September and October sowings gave early signs of failure. The lower temperatures, particularly of October, resulted in poor germination, and the seedlings which did appear were not more than 1 in. high, making a poor cover, by the onset of the winter. The October-sown seedlings had barely passed the cotyledon stage by December.

Spray effects.—By a week after the application of the December tar oil spray the outer leaves of the plants of the July and August sowings—those directly exposed to the spray—were withered and of a yellowish tinge. A fortnight later these leaves were brown and dead, but the inner leaves, those of the crown, after a temporary check, continued their growth as soon as weather conditions allowed. Some plants died later, however, probably through the combined effect of the sprays and cold weather.

The September- and October-sown seedlings were much more severely damaged by the spray (Fig. 1, Plate I). At first they lay flat, showing an oily appearance, and soon most of them were dead. The October-sown seedlings were entirely killed within a fortnight after the spray application in both years. The reaction of certain weeds, which, in the absence of competition, occupied much of the October-sown plots, was also noted. Grasses, mainly *Poa annua*, were not severely affected, except for a yellow-green oily appearance of their leaves and a temporary check to their growth ; but chickweed plants (*Stellaria media*) were killed outright.

In these plots, where growth was sparse, counts were made of dead earthworms lying on the surface after the tar oil spraying. A week after spraying, 8 to 10 dead earthworms per sub-plot were found. This kill, which would amount to about 20,000 per acre, may clearly have an undesirable effect on earthworm activity in the soil. The killing of earthworms by tar oil washes in orchards has been obvious for many years ; nevertheless many worms seem to survive each year. Accurate information on the net effect of tar oils on the soil is badly needed.

The reaction of the crimson clover seedlings to the January tar oil spray was more or less similar to their reaction to the December one. The February tar oil had a markedly less caustic

effect on the plants, particularly those sown in July and August (Fig. 2, Plate I). This is shown in the figures in Tables I and II, which will be discussed later.

The dinitrocresol spray had a somewhat milder effect than tar oil, both on the leaves and the plants. Most of the plants had their outer leaves scorched, and they suffered some check, but only a few of the July and August sown plants were killed. More of the September-sown plants and nearly all the October-sown ones were killed, however.

The petroleum oil, which in normal practice would follow a tar oil wash when control of capsid bug and red spider was required, was applied to separate plots in this trial in order to determine its effect independently of that of the tar oil. It proved to be the mildest of the sprays tested ; not even the October-sown seedlings were killed by it, although some of their leaves showed a superficial scorching, and there was some check to growth. This was more noticeable in 1943, when the petroleum was applied in February, than in 1944, when it was applied in March.

Cover crop yields.—The effects of time of sowing and spraying on the crimson clover were reflected in the height of the plants, in the area occupied by them and in the yield of fresh material. All these were recorded, but to save space, only the last two are presented in Table I. The differences in plant height were, in general, similar to those in fresh weight, but in spite of the conspicuous differences in height at the time of cutting, in May, all the plants were at the same stage of their flowering phase.

TABLE I.

Crimson clover. Effect of time of sowing and spraying.

Date of sowing.		Tar oil in Dec.	Tar oil in Jan.	Tar oil in Feb.	Dinitro-cresol in Feb. or March.	Petroleum oil in Feb. or March.	Un-sprayed.	Mean.
1942.								
July.	Fresh weight lb.*	2·12	1·80	2·92	2·72	2·92	3·37	**2·64**
	Area covered % ..	*56·2*	*51·2*	*62·5*	*71·2*	*74·2*	*81·7*	*66·2*
Aug.	Fresh weight lb.	3·45	3·62	4·52	3·82	4·05	4·62	**4·01**
	Area covered % ..	*80·0*	*67·5*	*93·0*	*95·2*	*99·0*	*99·0*	*88·9*
Sept.	Fresh weight lb.	0·10	0·07	0·65	1·00	2·03	3·52	**1·23**
	Area covered % ..	*2·5*	*2·3*	*22·5*	*42·5*	*85·0*	*90·8*	*40·9*
Oct.	Fresh weight lb.	0	0	0	0	0·35	0·72	**0·18**
	Area covered % ..	*0*	*0*	*0*	*0*	*20·7*	*53·7*	*12·4*
Mean.	Fresh weight lb.	**1·42**	**1·37**	**2·02**	**1·88**	**2·34**	**3·06**	
	Fresh weight as % of control ..	46·4	44·8	66·0	61·4	76·5	100·0	
1943.								
July.	Fresh weight lb.†	2·27	1·85	1·95	2·32	2·42	2·42	**2·20**
	Area covered % ..	*98·7*	*83·7*	*95·0*	*100·0*	*100·0*	*100·0*	*96·2*
Aug.	Fresh weight lb.	1·57	1·30	1·70	1·90	2·45	2·82	**1·96**
	Area covered % ..	*78·7*	*57·5*	*85·0*	*91·2*	*96·2*	*88·7*	*84·5*
Sept.	Fresh weight lb.	0·25	0·35	0·85	0·90	2·17	2·42	**1·16**
	Area covered % ..	*16·2*	*23·7*	*51·2*	*60·0*	*85·0*	*88·7*	*54·1*
Oct.	Fresh weight lb.	0	0	0·02	0·02	0·07	0·22	**0·05**
	Area covered % ..	*0*	*0*	*1·7*	*1·2*	*8·0*	*15·0*	*4·3*
Mean.	Fresh weight lb.	**1·02**	**0·87**	**1·13**	**1·28**	**1·78**	**1·97**	
	Fresh weight as % of control ..	51·8	44·1	57·4	65·0	90·4	100·0	

* Fresh weight recorded May 20th, 1943. % area recorded March 31st, 1943.
† Fresh weight recorded May 23rd, 1944. % area recorded May 23rd, 1944.

The area occupied by the plants was found with the aid of a sampling grid, 20 cm. square, subdivided into 100 squares, similar to those used for pasture analysis (Fenton, 1933). The sample for yield was taken from an area two feet square in the centre of each sub-plot.

It can be seen from Table I that the July and August sowings gave by far the best results for plants sprayed with winter washes. Where no sprays were applied the September sowing also gave a good yield of green material ; but October-sown plants were a failure both with and without spraying.

Because of the almost complete failure of the late sown plots, the September and October sowings of 1943 and the October sowing of 1944 were excluded from the statistical analyses. Analyses of the remaining figures showed little interaction between the effects of time of sowing and time of spraying, and the two factors can therefore conveniently be studied independently, from the means of the various sprays and months. The analyses showed that in 1943 the August sowing was significantly ($P=0\cdot05$) better than the July one in yield of fresh material, area covered, and height of plant. In 1944, the July sowing was significantly the best in area covered and height of plant, but was not significantly better than the August sowing in yield of fresh material. The September sowing was significantly worse than the August one in all three measurements.

All the sprays reduced the growth and yield of the plants, as compared with the unsprayed control, but not all the differences were significant. In 1942-43 tar oil in December and January, and dinitrocresol in February, significantly reduced the weight of fresh material, but tar oil in February did not. In 1943-44 the February tar oil, though again the least harmful of the tar oil applications, did cause a significant reduction in cover-crop yield. In this year the dinitrocresol (applied in March) gave a result slightly, but not significantly, better than the February tar oil.

The effects of the petroleum spray were not significantly different from the control in either year.

Winter oats and tares.

With the oats plus tares, all three sowings gave good stands capable, if not sprayed, of producing heavy yields of fresh material (Fig. 5, Plate II). The month of sowing had a definite effect on the composition of the sward. Thus, the oats and tares sown in August gave a sward consisting almost entirely of tares, in both years ; for the thermophilic tares, making use of the high temperatures of August, smothered the oats, with the result that only a few oat plants, situated on the margins of the plots where there was less competition, survived. The sward produced by the September sowing consisted of oats and tares in equal amounts. The October sowing produced more oats than tares.

In December, when the first tar oil was applied, the tares of the August sowing completely covered their plots and lay flat for lack of support, while the September and October sown plants nearly covered their plots and had average heights of 11 and 5 inches respectively.

The application of the tar oil in December or January had a severe effect, especially in 1942-43 (Fig. 4, Plate II.) Most of the plants developed a yellow-green, oily, appearance within a week after spraying, and they were dead a fortnight later. Tar oil applied in February, however, had a less serious effect, checking the plants but not killing them (Fig. 4, Plate II). In general the tar oil had less effect on the tares than on the oats ; nevertheless when it was applied in December, 1942 on the August-sown plots, which consisted entirely of tares, it practically wiped them out (Fig. 4, background).

The dinitrocresol sprays, while in general less damaging than tar oil ones, had a more harmful effect on the tares than on the oats (Fig. 6, Plate II). As a result of this differential effect plots sprayed with tar oil had relatively more tares than oats, when compared with the control (Fig. 5, Plate II), while those sprayed with dinitrocresol had more oats than tares.

Here again, as with the crimson clover, the petroleum oil had no harmful effect whatsoever, except for a temporary check of the growth of the plants.

Yields.—The weights of fresh material produced and the percentage of ground covered by the plants, determined as before, are shown in Table II. The heights, which followed the same general lines as the fresh weights, are omitted for the sake of brevity.

TABLE II.

Oats plus Tares. Effect of time of sowing and spraying.

Date of sowing.		Tar oil in Dec.	Tar oil in Jan.	Tar oil in Feb.	Dinitrocresol in Feb. or March.	Petroleum oil in Feb. or March.	Unsprayed.	Mean.
1942.								
Aug.	Fresh weight lb.*	0	0·20	0·82	0·70	1·75	2·7	**1·04**
	Area covered % ..	*0*	*10·2*	*2·5*	*18·7*	*71·2*	*78·7*	*34·0*
Sept.	Fresh weight lb.	0·55	1·97	3·55	3·15	3·72	3·75	**2·78**
	Area covered % ..	*5·0*	*23·2*	*97·5*	*100·0*	*100·0*	*100·0*	*70·9*
Oct.	Fresh weight lb.	0·57	1·72	3·30	3·00	4·0	4·22	**2·80**
	Area covered % ..	*10·2*	*75·0*	*95·0*	*100·0*	*100·0*	*99·5*	*80·0*
Mean.	Fresh weight lb.	**0·37**	**1·30**	**2·56**	**2·28**	**3·16**	**3·57**	
	Fresh weight as % of control ..	10·4	36·4	71·7	63·9	88·5	100·0	
1943.								
Aug.	Fresh weight lb.†	2·90	2·80	2·90	2·62	2·67	3·0	**2·81**
	Area covered % ..	*100·0*	*96·2*	*93·7*	*92·5*	*97·5*	*100·0*	*96·6*
Sept.	Fresh weight lb.	2·32	2·32	2·70	1·97	2·87	2·67	**2·48**
	Area covered % ..	*97·5*	*92·5*	*98·7*	*86·2*	*100·0*	*100·0*	*95·8*
Oct.	Fresh weight lb.	1·67	1·55	1·87	1·95	2·57	2·22	**1·97**
	Area covered % ..	*86·2*	*80·0*	*82·5*	*73·7*	*97·5*	*100·0*	*86·6*
Mean.	Fresh weight lb.	**2·30**	**2·22**	**2·49**	**2·17**	**2·70**	**2·63**	
	Fresh weight as % of control ..	87·5	84·4	94·7	82·5	102·7	100·0	

* Fresh weight recorded May 20th, 1943. % area recorded March 31st, 1943.
† Fresh weight recorded May 23rd, 1944. % area recorded May 23rd, 1944.

Table II shows that, although there are considerable differences between the two years as regards the August- and October-sown plots, the September-sown ones gave satisfactory results in both years. A statistical analysis of the fresh weights showed the August sowing of 1942 and the October one of 1943 to give significantly lower yields than the comparable September sowing. The August sowing of 1943 gave a heavier crop than the September sowing, but this difference is not significant ; in view of the unbalanced mixture resulting from sowing in August, and its failure in 1942, it is considered that the September sowing is the best for practical purposes.

As regards the effect of sprays, it is clear that tar oil applied in February did the least harm. The yields obtained under this treatment did not differ significantly from those of the control plots, and the crops were similar in composition. Dinitrocresol had a rather more harmful effect, though not nearly so severe as tar oil in December, 1942, and January, 1943. The petroleum oil plots could not be distinguished at the sampling time from the controls. The variation between the two seasons is further discussed in a later section.

RYE AND TARES.

Since preliminary observations on small plots of various crops grown as a cover-crop museum suggested that rye was more resistant to winter washes than oats, a series of plots using a rye plus tares mixture was tested with the various sprays in 1943-44. As there was only one replication of each treatment, the figures obtained cannot validly be compared with those from the other plots ; but it was quite obvious that the resistance of rye to winter washes was greater than that of oats, for even in those treatments where oats were severely affected the rye survived and gave a good yield. Fig. 3, Plate I, shows the December sprayed and the control plots. Spring-sown rye plus peas was one of the crops reported on in Part II of this series. The effect of autumn-sown rye and tares on fruit trees has not yet been tested, but this crop is clearly one worth further trial.

THIOCYANATE WINTER WASHES.

One other type of winter wash is worth mention in relation to its effect on under-crops, namely the thiocyanate oil mixture, noted by Shaw and Steer (1941) as likely to have a special value where market garden crops are interplanted (by implication because a less harmful effect would be expected). This wash is more expensive than tar oil or dinitrocresol, and is not at present in very common use. It was therefore not included in the main trials, but was tested in strips of a cover-crop museum in 1944. A commercial brand of this wash (Thiol) was used, being applied on March 15th, 1944, at 6 per cent., and compared with unsprayed strips and strips sprayed with 5 per cent. tar oil on February 23rd. Serial notes were made on the 33 different cover crops sprayed, and their height was measured periodically. These records showed that rye, lucerne, and established grasses generally, were practically unaffected by the thiocyanate wash ; oats, crimson clover, trefoil and rape, though slightly checked, were very much less damaged than by the tar oil. Tares, however, showed as much damage as from tar oil.

Final conclusions cannot be drawn from observations on these single plots in one season, but the results support the view that thiocyanate-oil washes are likely to have relatively small effects on most cover crops.

RELATION OF WEATHER CONDITIONS TO SPRAY DAMAGE.

It is interesting to consider how the reduction in damage resulting from delaying spraying till the end of the winter is related to weather conditions before and after the spray application. With this point in view summaries were made of the air temperature, number of frosty days and degrees of frost in the 30 days following each spray. Table III shows that in 1942-43 the December spray was followed by the coldest conditions, and the February spray by the warmest of that series. In 1944, however, an exceptionally cold period followed the February spraying

TABLE III.

Air temperatures for 30 days after the applications of tar oil spray, at East Malling.

Date of application of tar oil.	Mean max. °F.	Mean min. °F.	Total degrees of frost.	No. of frosty days.
1942-43.				
December 21st, 1942 ..	43·9	33·2	36	11
January 13th, 1943 ..	48·8	36·4	31	7
February 22nd, 1943 ..	50·4	36·6	17	6
1943-44.				
December 14th, 1943 ..	45·7	34·7	36	10
January 12th, 1944 ..	49·0	36·8	28	5
February 23rd, 1944 ..	45·0	31·0	74	20

giving much colder conditions than those in the 30 days following the December and January sprays. Visual observations showed that, under these conditions, much more severe damage occurred to the February sprayed plants in 1944 than in 1943, confirming the view that cold weather following the spray increases the damage. With the warmer conditions which came in March, however, the February sprayed plants made quite a good recovery, and even in 1944 produced larger crop weights than the December and January sprayed ones, both of crimson clover and oats plus tares. The contrast between the two seasons was particularly marked in the oats plus tares, and in Table II it can be seen that the severest damage was caused in the first season, when the winter weather was the coldest. In the second season, with rather warmer December and January weather, damage was much less severe. The much colder February conditions in the second season, however, did not result in a relatively smaller yield of this crop, compared with the control, whereas it did with the crimson clover. Thus it is seen that although intensity of cold is one factor in enhancing damage, the longer duration of poor growing conditions following the early winter sprays also contributes greatly to their severe effect. This, of course, is additional to the fact that at the earlier spraying the plants are younger and have smaller roots, crowns and food reserves, while at the later spraying they are not only larger but probably to some degree hardier, and in February or March will actually be resuming growth under conditions of longer daylight and higher maximum temperatures.

Thus the safest time to apply tar oil to crimson clover, and oats plus tares cover crops is by no means the period when the plant is most dormant.

CONCLUSIONS.

These experiments have shown that the success or failure of crimson clover and oats plus tares as autumn cover crops in orchards, depend very largely on the choice of time of sowing the seeds and time of application of the winter wash—two factors within the control of the grower.

For crimson clover, the most satisfactory results were obtained under East Malling conditions, by sowing in July or August, and delaying application of winter washes till February. Either tar oil in February or dinitrocresol in February or March may be applied to well established plants without seriously harmful results.

For oats plus tares, September proved to be the best sowing months, for this gives a balance of both species in a good condition for passing the winter. Again, delaying winter washes till February gave the most satisfactory results. Tar oil in February had slightly less severe effects than dinitrocresol in February or March.

Petroleum washes applied in spring had no lasting harmful effect. The greatest yields were obtained when winter washes were omitted entirely, and under such conditions the sowing period can be extended a further month ; but with the procedure outlined above satisfactory cover crops were grown without omitting the routine winter washing. On the other hand, if the cover crops were sown late and sprayed early, complete failure was assured.

It appears at least likely that the same general principles for minimizing winter wash damage could be applied to many other cover crops and vegetable and arable crops which may pass the winter in a green condition under fruit trees, namely to allow the undercrops to get well established before applying the spray, and to delay application of winter washes until growing conditions once more become relatively favourable, but having regard, of course, to the relative dormancy of the buds on the fruit trees.

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SUMMARY.

1. Autumn-sown cover crops may be seriously damaged by orchard winter washes. A test was therefore made of different possible times of sowing crimson clover (*Trifolium incarnatum*) and winter oats plus tares (*Avena sativa* and *Vicia sativa*), and of applying orchard winter washes, in relation to spray damage, growth and yield of the cover crop, in two seasons.

2. The crimson clover was sown in July, August, September and October, and the oats plus tares in August, September, and October. The five sprays, applied separately to all sowings, were: miscible tar oil wash in December, January and February, dinitrocresol-petroleum oil wash and field mixed petroleum oil-soap wash in February or March.

3. Choice of the most favourable times of sowing and spraying largely, though not entirely, obviated spray damage, and gave good results with both cover crops.

Time of sowing greatly affected yield, even in the unsprayed plots. Late sowing generally gave unsatisfactory results.

The least favourable sowing and spraying times resulted in complete cover-crop failure.

4. The best months for sowing crimson clover were July and August; and for winter oats plus tares, September. The least harm to the cover crops from winter washes was caused when these were applied as late as possible; tar oil in February, or dinitrocresol in February or March. Dinitrocresol was less harmful than tar oil applied early, and about equal to tar oil applied late. Dinitrocresol damaged tares and crimson clover more than oats. Tar oil, on the other hand, had a more severe effect on oats than on tares.

Petroleum oil, applied independently, did practically no harm to the plants.

5. A preliminary test, made with rye (*Secale cereale*) in place of oats, showed that it was superior to oats in its resistance to tar oil damage.

6. A preliminary test with a 6 per cent. thiocyanate oil wash suggested that this is markedly less harmful to many cover crops than tar oil or dinitrocresol.

7. It is concluded that vigour of the plant at the time of spraying, and intensity and duration of cold conditions following the spray application, are the main factors, apart from specific characters of individual cover crops and winter washes, controlling the reaction of cover crops to the harmful effects of winter sprays.

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PLATE I.

Fig. 1.
Foreground, Crimson Clover plots sown in September, 1942. On left, unsprayed; on right, sprayed with tar oil in December, 1943, causing almost complete elimination of plants. The vigorous plots in the background are July-sown ones.
Photograph taken April 13th, 1943.

Fig. 2.
Crimson Clover sown August, 1942. On left, unsprayed; on right, sprayed with tar oil in February, 1943, with only slight checking effect. The bare plots seen behind are October-sown ones.
Photograph taken April 13th, 1943.

Fig. 3.
Rye plus tares, sown September, 1943. On right, unsprayed; on left, sprayed with tar oil in December. Note very slight check to rye.
Photograph taken April 21st, 1944.

FIG. 4.
In front: Oats plus tares sown September, 1942. Sprayed with tar oil in December (left) and February, 1943 (right). Note severe effect of December spray, and mild effect of February one. Behind: August-sown plots, sprayed with tar oil in December (left) and unsprayed (right). Note predominance of tares, resulting from August sowing.
Photograph taken April 13th, 1943.

FIG. 5.
Oats plus tares sown in October, 1943. Unsprayed.
Photograph taken April 21st, 1944.

FIG. 6.
Oats plus tares sown in October, 1943. Sprayed with dinitrocresol in March, 1944. Note check to the tares is more severe than to the oats.
Photograph taken April 21st, 1944.

EXPERIMENTS ON VIRUS DEGENERATION OF HUXLEY STRAWBERRY

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Introduction.

A dwarfing disease of strawberries of the variety Huxley (synonyms Huxley's Giant, Brenda Gautry, Ettersberg 121, etc.), popularly known among growers as degeneration, breakdown, etc., has been commonly observed in England in field plantations of this variety for a number of years. The most obvious symptom is a reduction in size and vigour of the plant but, in addition, the leaves have a less glossy appearance than those of healthy plants and tend to be greyish-green in colour. The margins of the younger leaves are rather chlorotic, the chlorosis being more conspicuous in the autumn (Plate I, Fig. 1). The disease thus resembles Yellow-edge (Harris, 1933), but as has been shown (Harris and King, 1942), Huxley is tolerant to Yellow-edge and acts as a symptomless carrier of that disease. The deterioration of Huxley in the field with the development of symptoms reminiscent of Yellow-edge in Royal Sovereign has already been noted (Harris and King, 1942). Similar symptoms have occasionally been observed in the varieties Oberschlesien and Madame Lefebvre.

In 1938 a number of vigorous Huxley plants were received for use in experimental work and two of these were by chance grafted to Royal Sovereign plants infected with Yellow-edge and Crinkle. All of the Huxley plants, including those so grafted, were planted out in a field plot in 1939 and the two grafted Huxley plants were later observed by one of us (M.E.K.) to have developed symptoms of degeneration, typical of those found in the field. The other Huxley plants remained uniformly vigorous, and runners from the vigorous and the degenerate plants maintained this initial difference. In 1941 an experiment was set up in the field to investigate this further.

One row of Latin square in 1941, and same row in 1943.

1 = Degenerate Huxley plant (DH1).
2 = Vigorous Huxley plant (H2).
3 = Vigorous Huxley plant (H3).
4 = Virus-free Royal Sovereign (M40).
5 = Yellow-edge infected Royal Sovereign.
2A = H2 dwarfed by grafting to Y.E. (DH2).
3A = H3 dwarfed by grafting to Y.E. (DH3).
X = Plants grafted together.

Experimental.

Plants from two vigorous clones of Huxley (one, H3, infected with Yellow-edge of a very mild type, and the other, H2, infected with Yellow-edge of moderate severity) were grafted by the stolon inarching method (Harris and King, 1942) to Yellow-edge infected Royal Sovereign plants of the same stock as the plants used in 1938, ungrafted plants of the same two Huxley clones and ungrafted plants from a degenerate clone of Huxley (DH1) serving as controls. To equalize the effect of the root competition produced by the infectors (which were planted near the Huxleys to which they were grafted), uninfected Royal Sovereigns were planted adjacent to the controls. The Huxley plants and the Yellow-edge infected Royal Sovereign plants were known to be infected, in addition, with Crinkle.

The plants were arranged in groups of four pairs, each group consisting of one of the five treatments (Huxley clones H3 and H2—grafted ; H3, H2 and DH1—ungrafted control). These five groups were replicated in the form of a Latin square (see diagram). The plants were sprayed with nicotine insecticide from time to time, and, on one occasion (in 1943) were fumigated with nicotine vapour. These treatments were intended to prevent the aphis population from becoming too large and did not entirely prevent infestation, especially in 1944.

The appropriate grafts were made during July and August, 1941, and the average heights and spreads of the plants under the different treatments at this time and in the following summer and autumn are shown in Table I.

Table I.

Vigour of Huxley clones as expressed by mean height and spread of twenty plants.

Date of record.	H3 Not grafted. Height. in.	H3 Not grafted. Spread. in.	H3 Grafted to Y.E. Height. in.	H3 Grafted to Y.E. Spread. in.	H2 Not grafted Height. in.	H2 Not grafted Spread. in.	H2 Grafted to Y.E. Height. in.	H2 Grafted to Y.E. Spread. in.	DH1 Height. in.	DH1 Spread. in.
–/7/41 ..	2·8	7·9	2·8	6·9	2·7	7·7	2·9	8·1	1·8	4·8
–/6/42 ..	8·2	16·0	6·0	13·5	7·8	14·8	6·0	14·1	3·8	10·3
–/9/42 ..	7·8	16·8	5·9	13·6	7·5	15·0	5·9	13·7	4·0	9·4

It will be seen that, at the time of grafting, the vigour of the grafted and ungrafted samples (as expressed by the mean height and spread of 20 plants in each case) was similar. In June, 1942 (10-11 months after grafting), and in October, 1942, the grafted plants were less vigorous than the corresponding ungrafted ones, but more vigorous than the degenerate clone. A statistical analysis of the detailed records shows that the differences in heights and spreads between the grafted and ungrafted series are significant at $P=0{\cdot}001$.

A summary of symptom records made in September, 1942, is given in Table II.

Table II.

Symptoms exhibited by Huxley plants, 1942.

Treatment.	Number of plants showing: Severe Chlorosis.	Moderate Chlorosis.	Slight Chlorosis.	No Chlorosis.	Number of plants missing.
H3	0	0	1	18	1
H3 grafted ..	0	2	8	9	1
H2	0	0	2	16	2
H2 grafted ..	0	2	7	9	2
DH1	5	9	3	1	2

It will be seen that, while almost all of the ungrafted plants of the vigorous clones showed no marginal chlorosis, about half of the grafted plants showed slight or moderate symptoms. It was noted also that the symptoms of Yellow-edge on the Royal Sovereigns were more severe than they had been before these plants were grafted to the Huxleys.

This experiment verified the conclusion that degeneration was induced in certain clones of Huxley (infected with Yellow-edge and Mild Crinkle) by grafting them to a clone of Royal Sovereign also infected with Yellow-edge and Mild Crinkle. It seemed most likely that this phenomenon was due to the passage from the Royal Sovereign to the Huxleys of a virus (or viruses) not previously present in the latter. A reciprocal transmission to the Royal Sovereigns would also explain the increased severity of the symptoms on this variety. Alternative explanations were also examined. The loss of vigour in the Huxleys might have been caused purely by the process of grafting or, secondly, by some natural toxicity factor (or incompatibility) between Royal Sovereign and Huxley or, thirdly, by a purely quantitative or additive effect, (i.e. by the mere addition of Yellow-edge to Yellow-edge) or, fourthly, by an increase of virulence of the Yellow-edge virus in Royal Sovereign.

To examine these possibilities, vigorous Huxley plants were therefore grafted to *Fragaria vesca*, virus-free Royal Sovereign (Malling 40 clone), and vigorous (Mild Yellow-edge infected) Huxley, in addition to Yellow-edge infected Royal Sovereign and Mild Crinkle infected Royal Sovereign (M. 35 clone). These grafts were made in the glasshouse in 1942 and the Huxleys were planted out in the field in the spring of 1943. Heights and spreads in May, 1944, are shown in Table III.

Table III.

Effect of various grafts on vigorous Huxley clones.

Infection source.	Clone H3 Height. in.	Clone H3 Spread. in.	Clone H5 Height. in.	Clone H5 Spread. in.	Clone H6 Height. in.	Clone H6 Spread. in.
Royal Sovereign M.40 or *F. vesca* (Virus free)	6	14*	6	14	7	16
Huxley H3 (Mild Y.E.) ..	6	13†	–	–	8	14
Huxley H4 (Mild Crinkle) ..	6	13	–	–	–	–
Royal Sovereign M.35 (Mild Crinkle)	7	12	6	12	–	–
Royal Sovereign (Yellow-edge)	3	8	4	8	4	10

* Mean of 4 plants. † Mean of 2 plants.

It will be seen that each of the three plants grafted to Yellow-edge infected Royal Sovereign was dwarfed, and that those plants grafted to *F. vesca*, virus free Royal Sovereign, Mild Crinkle infected Royal Sovereign or Huxley, or Mild Yellow-edge infected Huxley, remained vigorous.

While the number of grafts is too small to allow of any final conclusion, it seems likely that degeneration is not caused by the Mild Crinkle associated with Yellow-edge in Royal Sovereign, by the mere process of grafting, by any factor present in virus free Royal Sovereign or by a purely additive effect. Further work on similar lines is in progress.

In 1943 the Royal Sovereign plants were removed from the field grafting experiment described earlier in this paper and, where suitable stolons were available, the Huxley plants were grafted to maiden Royal Sovereign (M. 40) or to vigorous maiden Huxley plants. In each group of four Huxley plants two were grafted to Royal Sovereign and two to Huxley, the selection being randomized (see diagram).

The Huxleys grafted to degenerate Huxleys became degenerate, while those grafted to vigorous Huxleys remained vigorous. The means of heights and spreads measured in November, 1944, are given in Table IV, allowance being made for plants missing.

TABLE IV.

Vigour and appearance of Huxley plants, 1944.

Clone to which grafts were made.	Mean height. in.	Mean spread. in.	No. of plants.	Degenerate plants.	Possible degenerate plants,	Vigorous plants.
DH1	3·3	10·1	4	4	0	0
DH2	4·5	11·5	10	5	4	1
DH3	5·0	13·0	7	1	3	3
H2	6·0	14·6	9	1	1	7
H3	5·7	14·3	7	0	3	4
Ungrafted ..	5·8	15·8	5	0	0	5

The differences in heights between plants grafted to DH1, plants grafted to DH2 and DH3, and plants grafted to H2 and H3, are significant ($P = \cdot 05$) and while the differences in spreads between DH2 and DH3, and H2 and H3 are not significant they suggest that grafting to degenerate plants has reduced spread also. Degeneration symptom records taken at the same time are also included in the Table.

The degenerate plants induced symptoms of Yellow-edge in the Royal Sovereign plants to which they were grafted, but these symptoms did not appear to be any more severe than those induced by plants of one of the vigorous clones (H2). Symptoms of Yellow-edge appearing on some of the ungrafted plants are believed to be due to natural transmission of virus by the vector *Capitophorus* (*Pentatrichopus*) *fragariae*. A summary of records made in November, 1944, is given in Table V.

TABLE V.

Appearance of Royal Sovereign plants, 1944.

Clone to which grafts were made.	Number of plants showing					
	No Y.E. symptoms.	Suspected Y.E.	Slight Y.E.	Moderate Y.E.	Severe Y.E.	Very severe Y.E.
DH1 (Degenerate clone)	0	0	0	2	2	0
DH2 (H2 plus Y.E.)	0	0	0	5	4	0
DH3 (H3 plus Y.E.)	0	0	0	4	2	0
H2	0	0	0	3	5	0
H3	0	1	2	3	3	0
Ungrafted ..	1	1	0	1	1	0

DISCUSSION.

The experiments show that a form of degeneration is transmissible from Huxley to Huxley by grafting and in the absence of any visible pathogen the disease is assumed to be caused by a virus or virus complex. The earlier experiments indicate that this virus is present in Yellow-edge infected Royal Sovereign, but the relation of degeneration in Huxley to Yellow-edge in

Royal Sovereign is not clear, since vigorous Huxleys can produce symptoms of Yellow-edge in Royal Sovereign of the same intensity as those produced by degenerate Huxleys. It is possible, of course, but unlikely, that the virus or virus complex causing degeneration is entirely distinct from that responsible for Yellow-edge in Huxley or Royal Sovereign.

A somewhat similar phenomenon of deterioration of a Yellow-edge tolerant variety (Premier) as a result of grafting to Royal Sovereign has been recorded in Canada (Harris and Hildebrand, 1937). The Royal Sovereign plants used by these workers were from a clone which was later shown to be infected with Mild Crinkle and it was considered by them that the deterioration was probably brought about by the action of this virus. There is no evidence, however, that degeneration of Huxley can be induced by infection with Mild Crinkle.

Possible explanations of the results described above are that two viruses or virus complexes exist, each of which produces symptoms of Yellow-edge in Royal Sovereign but only one of which produces degeneration of Huxley, or that the disease is caused by a more virulent strain of Yellow-edge produced by passing the Yellow-edge virus through Royal Sovereign, just as Carsner (1925) and Lackey (1932) have shown that the severity of the symptoms produced on sugar beet by the Sugar-beet Curly-top virus can be reduced by passage of the virus through *Chenopodium murale* and brought back to its original condition by inoculation of and re-isolation from *Stellaria media*. On the other hand, degeneration may be caused by a virus distinct from the Yellow-edge virus and the occurrence of this virus in Yellow-edge infected Royal Sovereign may be fortuitous.

Degeneration, as has been mentioned, shows similarities to Yellow-edge in that the chief symptoms of both diseases are dwarfing of leaf laminae and petioles, with marginal chlorosis. They differ in that, while Huxley is tolerant to Yellow-edge, it shows symptoms of degeneration. The disease also resembles in some respects Stunt disease (Zeller and Weaver, 1941). Symptoms of the latter are: short, erect petioles, small, cupped leaves with a dull upper surface and, sometimes, marginal chlorosis. As has been stated, the intensity of the chlorosis in degenerate Huxleys is variable and is scarcely noticeable at some seasons of the year. Presumably the expression of symptoms is dependent on environmental factors as has been shown for Yellow-edge in Royal Sovereign (King and Harris, 1942) and such factors may be less favourable to symptom expression in the U.S.A. Cupping of the leaves (a symptom of Stunt) has, however, not been noted in degenerate Huxleys.

Although the precise viruses involved in the phenomenon of Huxley degeneration are not yet identified, the complex concerned has now been shown to differ substantially from that normally present in vigorous Huxley plants. Therefore from the practical view-point of field-maintenance of healthy sources of runners, runner-beds of Huxley should be rogued for the symptoms described above in the same manner as those of Royal Sovereign are rogued for Yellow-edge and Crinkle symptoms.

Symptoms of virus degeneration may be confused with those of Verticillium Wilt which is of frequent occurrence in plantations of Huxley. Verticillium Wilt also causes marginal yellowing of the younger leaves but the chlorosis produced is yellower and more striking than the greenish yellow chlorosis of virus degeneration ; the vigour of infected plants is less affected, the outer leaves of wilted plants become brown and withered and the vascular tissues of the stem (crown) are brownish in colour.* Verticillium mycelium can also be observed in infected tissues and can readily be isolated (Wormald and Harris, 1938).

ACKNOWLEDGMENTS.

The authors are indebted to Mr. S. C. Pearce for the statistical layout and analyses of results and to Mrs. A. C. Painter who made some of the grafts.

* I. Isaac—private communication.

SUMMARY

A virus degeneration disease of cultivated strawberry (var. Huxley) in England is described. Symptoms are reduction in size and vigour of infected plants and a less glossy, grey-green appearance of the leaves. Marginal chlorosis of the younger leaves occurs, particularly in the autumn. The disease is graft-transmissible and has also been induced by grafting Royal Sovereign plants infected with Yellow-edge and Crinkle to vigorous Huxley plants also infected with Yellow-edge and Crinkle. It is not induced by grafting virus-free Royal Sovereign plants to vigorous Huxleys. The relation, if any, of the causal virus to the virus or virus-complex which causes Yellow-edge is unknown. The roguing of Huxley runner-beds for degeneration symptoms is advised.

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PLATE I.

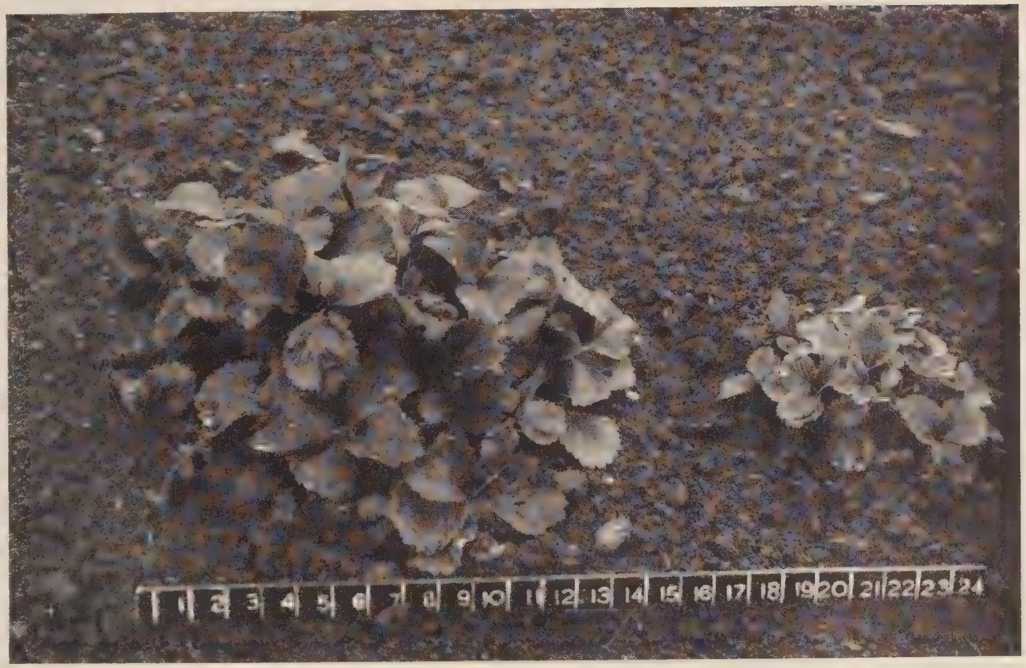

Fig. 1.

Two Huxley strawberry plants of the same age.
Left: Normal plant. Right: Degenerate plant.
Both were originally vigorous runners from the same clone. Normal plant grafted to vigorous Huxley and degenerate plant to degenerate Huxley, July, 1943.
Photograph taken November, 1944. Scale in inches. Panchromatic plate. 2x Yellow filter.

BOOK REVIEW

VIRUS DISEASES OF FARM AND GARDEN CROPS. By KENNETH M. SMITH, F.R.S. (Littlebury, 1945, pp. 94, illus., 10s. 6d.)

The crucial importance of plant virus diseases to producers of many agricultural and horticultural crops and to gardeners is now generally recognized by these industries. This is certainly due in part to the considerable advances in our knowledge of them and may even reflect an intensification of their onslaught. Be that as it may, the present volume claims, with good reason, to meet a growing need for a textbook treating of virus diseases from the point of view of the practical grower and of his advisers. Vital information on their identification and control, hitherto scattered through an extensive literature embedded in masses of data on the nature and properties of the viruses themselves, is here gathered together in convenient format—one of the better examples of wartime book production.

Because viruses are ultramicroscopic and cannot be cultured outside their living host-plant, diagnosis must largely depend on the plant symptoms produced. The special technique of identification by means of " Indicator plants ", using grafting, mechanical or insect modes of transmission is, therefore, described in Chapter I.

Chapter II enlarges on the subject of insect transmission concluding with a brief non-technical description of important vectors in the British Isles and a list of the diseases transmitted by each. The descriptions of vectors are supplemented in an appendix by an admirable series of drawings by Miss Margaret Short.

The remaining seven chapters deal with the diseases themselves grouped under their host-plants as follows : Potato ; Root crops ; Pulse and Pasture crops ; Vegetables ; Soft Fruit and Hops ; Ornamental Plants ; and Medical Plants and Weed hosts. The causal virus or viruses of each disease or composite disease are clearly distinguished, as far as present knowledge allows, thus displaying the relations between diseases having viruses in common. Succinct descriptions of symptoms are followed by a summary of the latest information on practical control measures and each chapter concludes with a select list of references to the relevant scientific papers. The textual descriptions of symptoms are further supplemented by sixteen plates of excellently chosen and reproduced photographic illustrations and ready reference is ensured by a table of contents and an index. The book is eminently readable throughout and furnishes the grower and the adviser in plant diseases with a handy everyday vade mecum.

Inevitably in the first edition of such a work minor errors and omissions are to be found, and apropos the diseases of soft fruit (Chapter VII) the following may be worth noting. It must be regretfully disclaimed (p. 69) that East Malling Research Station has still available an almost virus-free clone of Lloyd George raspberry. There are, however, two or three exceptionally vigorous sources of supply elsewhere which, because careful propagation is effected in relative isolation, contain only comparatively innocuous virus. Finally (p. 72), the strawberry aphis, *Capitophorus fragariae* Theob. has been conclusively shown to transmit Strawberry Crinkle (Massee, 1942, JOURNAL OF POMOLOGY, XX, 42-8). A description of this important aphid might usefully be added to future editions.

R. V. HARRIS.

VIRUS DISEASES OF THE STRAWBERRY

I. THE FIELD PROBLEM IN NORTH WALES

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Introduction.

The decline in yield of commercial strawberry plantations in the Dee valley, Denbighshire, during the last 30 years has reduced the area under the crop there from about 750 acres in 1914 to 250 in 1937, and to about 50 in 1945.

Study of the problem began in 1938 and it soon became evident that edaphic and cultivation factors had little to do with the degeneration but that it was due to virus diseases. Both in the Dee and Conway valleys it appeared that the onset of serious degeneration coincided with the introduction of new varieties, some of which have since proved to be symptomless carriers of viruses. Several of these at first showed great vigour, and as the old popular varieties degenerated the search for new ones was intensified. The result is, however, that Royal Sovereign has been almost irretrievably ruined, and even the vigorous carriers are now degenerating. The present paper covers the main advisory aspects of the problem, but the etiology of the clinical categories known as Crinkle, Yellow-edge and Dwarfing is not discussed.

Massee (1935*a*, 1938*a*, 1942) showed that the strawberry aphis, *Pentatrichopus* (*Capitophorus*) *fragariae* (Theob.), was a vector of both Crinkle and Yellow-edge so that the first need was to study the ecology and biology of this aphis under North Wales conditions and to survey commercial strawberry plantations there to ascertain whether there was any correlation between aphis populations and crop degeneration. The aphis study was begun by Dr. I. Thomas and Mr. F. H. Jacob in 1938 and continued by one of the present writers (C.A.W.) from 1939 onwards.

To collect data on aphis flight from commercial strawberry areas, a number of small plots in isolated districts of Anglesey and Caernarvonshire were planted with vigorous, symptomless stocks of Royal Sovereign and other varieties. It was hoped that some plots would remain free from the aphis and would not only serve as a nucleus for propagating vigorous runners for use in commercial areas, but also help in assessing the role of the aphis in causing degeneration. These objects have largely been secured ; all the plots remained aphis-free until 1943 (since when a small number of *P. fragariae* have been recorded on some plots), and a very promising industry of healthy runner production has been started.

Field surveys of disease incidence, depending on visual inspection, have, of course, only a limited value even for sensitive varieties, and far less for solving the problem of the breakdown of carriers. A study of the virus content in both types of varieties was therefore also begun in 1938, the results of which and the data collected during the aphis survey will be reported on separately.

Disease incidence in commercial plantations.

1. *Classification of symptoms.*

A preliminary disease survey in 1938 showed that whilst Crinkle and Yellow-edge were prevalent many plants showed merely severe stunting. Eventually, the following clinical groups were segregated without any implication as to their virus content or that they indicate intermediate steps through which a mildly affected plant passes to a severely degenerate form.

(i) *Dwarfing.* (*a*) *Severe*, or (*b*) *Moderate*, according to the degree of stunting as compared with apparently healthy plants of the same variety in the same plot. Symptoms of Crinkle or of Yellow-edge either absent or slight.

(ii) *Yellow-edge.* (*a*) *Severe*, if showing the full flattened, stunted habit or, (*b*) *Moderate*, if the most pronounced symptom is marginal chlorosis.

(iii) *Crinkle.* (*a*) *Severe*, when stunting approximates to that described under (i (*a*)), and is accompanied by considerable leaf malformation and distortion, with chlorotic and necrotic spotting of the laminae; (*b*) *Moderate*, if a fair degree of vigour accompanies such spotting and distortion ; (*c*) *Mild*, when plants are large and vigorous, often indeed of full size for the variety under the conditions of cultivation present, but with chlorotic or pellucid spotting of young leaves when viewed by transmitted light.

(iv) *Symptomless plants.* Vigorous in growth and entirely free from symptoms of Crinkle or of Yellow-edge.

Plants were classified according to the predominant symptoms shown, since more than one category might be present. Thus, plants showing marked dwarfing would fall into (i (*a*)) though there might be evidence of slight infection with Yellow-edge or Crinkle. Similarly, Yellow-edge plants almost invariably exhibit the pellucid spotting described as Mild Crinkle. Comparisons were always made with apparently normal plants of the same variety and age growing where possible in the same plot ; but even so, the personal factor could not be ignored, and difficulties of interpretation were often experienced. Similar problems have presented themselves to other workers, e.g. Harris (1937*a*) and Beaumont and Staniland (1945). The method adopted in the present survey was to examine some twenty samples, each five yards long along rows, as evenly distributed as possible over the whole crop, the total plants in each category then being expressed as a percentage of the total plants examined. The writers confirm King and Harris (1942) that September and October are the best months for survey work involving an estimate of Yellow-edge.

2. *The strawberry aphis in relation to degeneration.*

Text-figure 1 shows the fluctuation in population of the strawberry aphis during the period 1938-44, as well as the percentages of visible virus diseases during the years 1940-44. The latter are the result of examining many plots of different varieties and ages and there is no obvious relation between the total amount of disease and the aphis population in any one year. It is difficult to distinguish symptomless from mildly-infected plants of the same vigour ; moreover, perhaps one-third of the plots consisted of new runners, selected for their vigour. Such variation in total disease as the text-figure shows is largely due to this selection, and it is most evident towards the end of several years of low aphis incidence, i.e. in 1942. There is little risk of growers purchasing obviously degenerate runners, hence the percentages of plants in the serious disease categories reflect degeneration due to local factors.

From the text-figure it is clear that a correlation exists between the percentages of seriously diseased plants and the aphis population ; in 1940-42 aphis counts were low and so were percentages of severe degeneration ; the aphis peak years were 1943 and 1944, when degeneration was also high. Disease counts in 1938 were on a somewhat different basis, but the crops showed up to 23 per cent. of severe Crinkle alone, and many beds were ploughed in during the autumn and following spring, showing that the relation between aphis population and degeneration was as marked then as in later years. The winter of 1942-43 was unusually mild, aphis numbers rapidly increased, and a very early and heavy infestation of the plantations occurred ; hence the enormous increase in severely degenerate plants from the relatively few disease foci of the previous autumn. Many beds were ploughed in during 1943, but far more degenerate plants remained as sources from which the smaller peak of aphides of 1944 could spread disease than in the previous year, and this was doubtless responsible for the almost hopeless condition of the crops in 1944.

3. *Age of bed in relation to degeneration.*

In years of relatively low virus spread (e.g. 1940-42), degeneration symptoms were generally more severe in the older than in the younger beds of a given stock. This is shown in Table I, which gives figures from the various categories in one- and two-year-old beds of two different stocks of Huxley examined in October, 1940. The younger beds were planted with runners from the older ones, and the two were adjacent. Increased degeneration in the older beds is revealed by the higher incidence of one or more of the more severe symptom categories ; in this variety the chief degeneration symptom was Dwarfing, though almost all the most vigorous plants showed the pellucid spotting of Mild

Crinkle. Table II gives similar data for two stocks of Royal Sovereign but here the degeneration was almost wholly confined to the Crinkle categories. The two-year-old beds of both varieties

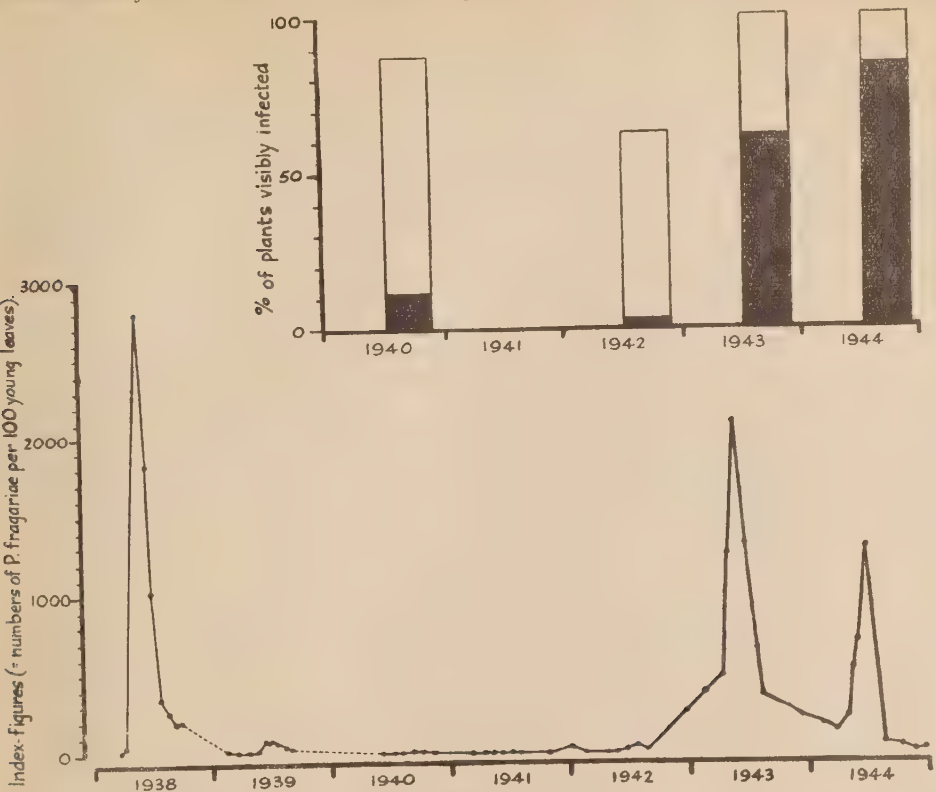

FIG. 1.

Lower graph shows average populations of *Pentatrichopus fragariae* (Theob.) on strawberries at Holt, Denbighshire, in the years 1938-44.

Upper graph gives the average incidence of total (upper limits of rectangles) and of severe (black zones) visible virus infection in strawberries at Holt in the years 1940-44.

had much more than the average percentage of severe symptoms recorded in that year (Fig. 1) whilst this was counter-balanced by the low percentage of severe disease in the one-year-old stocks.

TABLE I.

Incidence of degeneration in beds of different ages, 1940 (Huxley).
(Figures=percentage of total plants examined).

Disease.	Stock (*a*) Huxley (I).		Stock (*b*) Huxley (II).	
	1-year-old.	2-year-old.	1-year-old.	2-year-old.
Severe Dwarfing	7	28	4	22
Moderate Dwarfing	34	32	52	58
Severe Yellow-edge	1	2	1	2
Moderate Yellow-edge ..	11	7	5	4
Severe Crinkle	1	1	0	0
Moderate Crinkle	6	3	1	1
Mild Crinkle	39	28	38	14
Symptomless	2	1	0	0

TABLE II.

Incidence of degeneration in beds of different ages, 1940 (Royal Sovereign).
(Figures=percentage of total plants examined).

Disease.	Stock (c) Royal Sovereign (I).		Stock (d) Royal Sovereign (II).	
	1-year-old.	2-year-old.	1-year-old.	2-year-old.
Severe Dwarfing	0	0	0	0
Moderate Dwarfing	1	0	0	0
Severe Yellow-edge	1	0	4	10
Moderate Yellow-edge ..	2	0	3	3
Severe Crinkle	10	18	35	61
Moderate Crinkle	45	47	50	27
Mild Crinkle	41	35	9	0
Symptomless	0	0	0	0

On the other hand, in years of high virus spread (1943 and 1944), degeneration in maiden beds was rapid and extreme ; a very serious matter for growers, since there were no runners worth propagating. Table III gives degeneration data from typical maiden stocks in the Holt area of Denbighshire in December, 1943, though at this late period in the year the figures for Dwarfing were relatively higher, and those for Yellow-edge correspondingly lower, than those obtained three months earlier.

TABLE III.

Incidence of degeneration in three maiden beds at Holt, 1943.
(Figures=percentage of total plants examined).

Disease.	Huxley.	Royal Sovereign.	Oberschlesien.
Severe Dwarfing ..	40	63	86
Moderate Dwarfing ..	19	14	5
Severe Yellow-edge ..	16	3	7
Moderate Yellow-edge	26	4	2
Severe Crinkle ..	0	12	0
Moderate Crinkle ..	0	4	0
Mild Crinkle	0	0	0
Symptomless	0	0	0

Detailed surveys were not made in 1944, degeneration being so severe that rapid estimates of Severe Yellow-edge and Severe Crinkle were considered sufficient. In August and September from 60-80 per cent. of severe symptoms, mostly Yellow-edge, were recorded in stocks of Royal Sovereign (M. 40) which had been virus-free when purchased nine months earlier. Similarly, much Yellow-edge and Dwarfing occurred in Huxley (M. 43) plants derived from Nuclear Stock nurseries in the previous autumn. Many Royal Sovereign maiden beds were ploughed in after fruiting in 1944, and it will be seen that such beds shared fully in the degeneration so evident in 1943 and 1944 (Fig. 1).

Such rapid degeneration over a wide area of apparently healthy, vigorous, maiden stocks can certainly not be explained by manurial differences between one-year-old and older stocks or by a gradual loss of balance between plant and virus, leading to an intensification of symptoms, though these factors may play a minor part. The only other factor obviously operating is the coincidence in time between high populations of the aphis vector and this degeneration of maiden stocks. Thus, degeneracy—apart from mild pellucid spotting of the foliage—must be due to a virus brought by the aphis to vigorous plants in which it was not already present. A single season of high aphis population, provided disease foci are at hand, makes the previous autumn selection of vigorous runners useless and the grower must gamble on the chance of getting good runners from some other source.

4. *Varietal differences in symptom expression.*

Strawberry varieties are well known to differ in the symptoms associated with degeneracy (Harris (1937*b*) ; Rogers *et al.* (1939)), and the differences recorded in North Wales correspond well with those found in south-east England. Degeneration in Huxley takes the form of marked dwarfing of the plants, severe types of Crinkle and Yellow-edge being uncommon in it. This dwarfing is still more evident in Western Queen and is also characteristic of Noble and Madame Lefebvre. Royal Sovereign shows high sensitivity to Crinkle, and a symptomless plant is a rarity. Of other varieties, only Tardive de Leopold approaches Royal Sovereign in severity of Crinkle symptoms, whilst Oberschlesien and Pillnitz are intermediate types since, although dwarfing is common, it is more usually accompanied by Yellow-edge in them than in Huxley. The varietal sensitivity for North Wales is given in Table IV, whilst typical data on which these groups are based will be found in Table V.

TABLE IV.

Varietal symptom expression in North Wales.

Susceptible or Sensitive.	Intermediate.	Carriers or Tolerant.
Royal Sovereign. Tardive de Leopold.	Oberschlesien. Pillnitz.	Huxley. Noble. Madame Lefebvre. Western Queen.

TABLE V.

Incidence of degeneration in varieties at Holt, 1940.

Disease.	Average of maiden beds.			Two-year-old beds.			
	Huxley 4 beds.	Western Queen 2 beds.	Oberschlesien 3 beds.	Pillnitz, stock 7 years in Holt.	Tardive de Leopold, 10 years in Holt.	Madame Lefebvre, ? years in Holt.	Noble, 2 years in Holt.
Severe Dwarfing	3	23	2	8	0	80	46
Moderate Dwarfing	43	48	25	68	0		44
Severe Yellow-edge	1	1	6	2	1	2	0
Moderate Yellow-edge	10	2	33	5	4	9	1
Severe Crinkle	1	0	0	3	18	0	0
Moderate Crinkle	3	1	1	6	50	2	0
Mild Crinkle	35	4	10	1	28	0	0
Symptomless	5	21	25	7	0	7	9

SEARCH FOR POSSIBLE VIRUS VECTORS.

1. *General.*

Although field surveys showed a definite correlation between the population of *Pentatrichopus fragariae* and strawberry degeneration, it was recognized that other members of the strawberry fauna (e.g. *Macrosiphum solanifolii*) often showed a parallel fluctuation in numbers, and the possibility of one or other of these acting as a vector could not be ignored. Massee (1936) had no success with strawberry aphides other than Pentatrichopus (Capitophorus), or with a white-fly, a species of leaf-hopper, the tarsonemid mite or the red-spider mite. Plakidas (1927) was equally unsuccessful in transmitting strawberry Xanthosis (closely related to Yellow-edge according to Harris, 1933) by the red-spider mite. The present writers therefore confined their first studies, in 1938, to Aphididae found infesting commercial strawberry beds in North Wales. These were *Macrosiphum solanifolii* (Ashm.) ; *Aulacorthum solani* (Kalt.)

(=*Myzus pseudosolani* Theob.), *Myzus persicae* (Sulz.) ; and *M. pelargonii* (Kalt.). To these were added *Myzus circumflexus* (Buckt.) (although only a single individual had been found on strawberry), *Myzus ornatus* Laing (used in 1939 although it had not then been recorded on the crop), and, of course, the known vector, *P. fragariae* (Theob.).

All stocks of aphides were kept for at least three days on *Fragaria vesca* to determine their initial virus freedom, and all proved to be non-viruliferous by this test. Two diseased Royal Sovereign plants, showing typical Yellow-edge and severe Crinkle, respectively, served as sources of infection ; on detached leaves of these the aphides under test remained for at least three days before being transferred to healthy, non-clonal, indicator plants of *F. vesca*. One pair of indicators was used for each aphis-disease combination. During infection-feeding the detached leaves were housed in the apparatus illustrated in Fig. 2. Aphis transfers to each

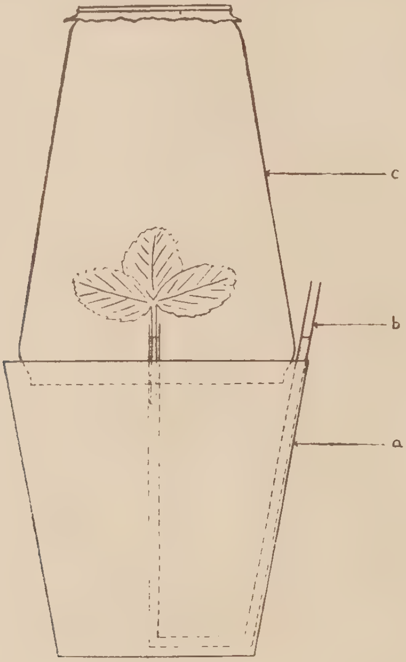

FIG. 2.

Apparatus used in feeding aphides on detached leaves. (*a*) Flower pot containing soil or sand ; (*b*) glass U-tube in which leaf is inserted and supplied with water as required ; (*c*) glass lamp-chimney covered with cellophane.

indicator, continued from October until the end of November and the total number used during the five weeks of the experiment is shown for each species in Table VI. A repeat test in January, 1939, had only small modifications, *Myzus ornatus* being included to replace *M. pelargonii* and *P. fragariae*. Also, the infection-feed was continued for four days and the aphides were fed on clonal *F. vesca* plants for three weeks only. The total number of aphides used and the highest number transferred on any one occasion are given in Table VI.

The only indicator plants (*F. vesca*) to develop symptoms were those on which *P. fragariae* had fed. Of these, the two infected from the Crinkle source and one from Yellow-edge gave signs of infection after three weeks, and ultimately developed severe symptoms of the Crinkle type. No significant differences in symptoms were observed from the two infection sources, though later experiments (to be described elsewhere) in which virus-free Royal Sovereign plants were substituted for the *F. vesca* indicators confirmed Massee's (1935*a*, 1938*a*, 1942) finding that *P. fragariae* could transmit both diseases. It seems reasonable to conclude

TABLE VI.

Number of aphides of various species transferred to F. vesca.

Aphis species.	Severe Crinkle infector to indicator plants.				Yellow-edge infector to indicator plants.			
	1938.		1939.		1938.		1939.	
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Pentatrichopus fragariae	18	18	—	—	3	3	—	—
Macrosiphum solanifolii	12	13	68 (47)*	67 (47)	4	6	44 (34)	43 (34)
Aulacorthum solani ..	6	7	84 (35)	84 (35)	20	20	57 (29)	57 (29)
Myzus persicae	3	4	61 (25)	60 (25)	2	3	24 (15)	24 (15)
Myzus circumflexus ..	28	28	63 (20)	63 (20)	12	19	49 (28)	49 (28)
Myzus pelargonii ..	13	13	—	—	3	3	—	—
Myzus ornatus	—	—	38 (14)	38 (14)	—	—	—	—

* Bracketed figures = highest number used in any single transfer.

therefore that *P. fragariae* is the only species of aphis recorded on cultivated strawberry that is implicated in the degeneration of strawberries in North Wales.

2. *The Genus Pentatrichopus.*

It was possible that species closely related to *P. fragariae*, but not recorded on strawberry, might prove to be strawberry virus vectors. To disentangle the confused nomenclature (and hence the relationships) of the English strawberry aphis is no easy matter. Ris Lambers (1933) initiated the controversy by identifying the British species with the American *Myzus fragaefolii* (Cockl.), and equating both with *Pentatrichopus potentillae* (Wlk.). Massee (1936) quotes Laing as supporting his acceptance of the identity of *Capitophorus fragariae* and *Myzus fragaefolii* under the name of *C. fragaefolii* (Cockl.), but within two years both British entomologists reverted to the old name of *C. fragariae* (Theob.). Strong evidence has been advanced by Thomas and Jacob (1940) for their belief that, whilst the English strawberry aphis belongs in fact to the genus Pentatrichopus it is quite distinct from *P. potentillae*; they propose that the name *P. fragariae* (Theob.) should replace *C. fragariae*.

The correct identification of a vector of virus diseases is of practical as well as of mere academical entomological interest. The genus Pentatrichopus is separated from Capitophorus by minor morphological differences only, but the life-cycles of members of the two genera differ widely. Members of the genus Pentatrichopus (of which there are three British species (*P. fragariae, P. potentillae* and *P. tetrarhodus*) are, in the strict sense, non-migratory, and each species is largely restricted to one specific host plant. The genus Capitophorus, however, includes several British species which migrate from a winter host to different summer food plants, though none has been recorded on strawberry. The strawberry-virus potentialities of species of Capitophorus have not yet been tested and it is not known to what extent the marked biological differences from Pentatrichopus may affect their ability to act as a vector. It is certain, however, that vector ability is not determined by similarity of life cycles within a genus, for the present writers (1941) showed that *P. potentillae*, which is normally confined to silverweed (*Potentilla anserina*) and survives, and feeds, for a few days on strawberry, is not capable of transmitting Crinkle. On the other hand, *P. tetrarhodus* (naturally specific on spp. of Rosa) readily feeds for at least three weeks on cultivated strawberry and on *F. vesca* (Thomas and Jacob, 1940), and was shown by the writers (1941) to be an efficient vector of Crinkle. These conclusions were reached on the results of the following experiments in 1940 and 1941 :

Tests with Pentatrichopus potentillae.—(*a*) In July, 1940, 20 adult apterae were kept for 44 hours on a severe Crinkle-affected Royal Sovereign plant, after which the 16 survivors were transferred to two *F. vesca* indicators. The insects certainly fed on the young leaves of the diseased strawberry, but neither the supposedly viruliferous aphides nor the control sample survived for more than a few days on *F. vesca*. The indicators showed no symptoms during the four months they were under observation.

(*b*) In a repeat test in August, 1940, nine individuals were transferred to each of two *F. vesca* indicators after spending 20 hours on the same severe Crinkle-affected source as in (*a*). At least four were noted as feeding after a lapse of 8 hours, but all died within 11 days after transfer to the indicators, and no symptoms developed on these plants.

(*c*) More conclusive evidence of the aphides having fed on the test plants was desirable before accepting the inability of *P. potentillae* to act as a vector. A numerous stock of the aphis was therefore divided into four lots in 1944. Lot A was used without preliminary starvation ; Lot B was starved for 19 hours whilst exposed to light, and Lot C for the same period in darkness ; Lot D was starved for 42 hours whilst exposed to light. The unstarved insects fed very little, if at all, when transferred to a leaf detached from a severe Crinkle-affected Royal Sovereign plant for 24 hours, and very few survived for two days on *F. vesca* indicators. Lots B and C, after 19 hours starvation, began feeding at once on the infector leaf on which they remained for 5 hours ; they continued to feed on the indicators but died within three days. It was noted that the insects starved in darkness showed even greater activity in feeding than did those exposed to light. Finally, most of Lot D survived their 42 hours of starvation and fed well for 24 hours on infector leaves, many continuing to do so for a further 24 hours on the indicator plants of *F. vesca*. No evidence of transmission was obtained in any of these trials, although a parallel test with *P. fragariae*, without preliminary starvation, produced all the usual symptoms on the indicators. Altogether 78 individuals of *P. potentillae* were used, with negative results.

Tests with Pentatrichopus tetrarhodus.—These trials were similar to the unstarved tests described for *P. potentillae*. The first test in 1940 resulted in two out of four *F. vesca* indicators developing symptoms indistinguishable from those obtained with *P. fragariae*. In 1941, six out of nine indicators became infected, whilst no symptoms appeared on control indicators used to determine the initial health of the insects. All the individuals appeared to feed well on the infector leaves for from 24 to 48 hours, and for several days on the indicators, on which, however, they eventually died out. A further trial was made in 1944 when both *F. vesca* and virus-free (M. 40) Royal Sovereign were used as indicators. The results confirmed the ability of the species to transmit a Crinkle virus to *F. vesca* ; but no symptoms developed on the Sovereigns, a result which was attributed to the poor feeding of the insects on the cultivated strawberry. The conclusion seems justified that, of the three species with a similar biology, *P. fragariae* and *P. tetrarhodus* are efficient vectors of a strawberry virus, whereas *P. potentillae* is not. This difference appears to be independent of the palatability of the test plant, for the last named species failed to transmit when feeding voraciously after starvation.

Virus transmission experiments with *Pentatrichopus fragariae*.

1. *Non-inheritance of virus-infectivity*.

Experiments were carried out in 1939-40 and 41, to determine the virus condition of larvae of *P. fragariae* at birth. After ascertaining that larvae were not commonly deposited in the absence of food, e.g. in collecting tubes, some 60 Crinkle-viruliferous adult apterae were transferred to four healthy *F. vesca* plants, and 54 of their larvae were placed on eight similar indicators within 24 hours after birth, five being the smallest number on any one indicator. No symptoms appeared on these indicators during the six months they were under observation, whereas the four plants receiving the original adults all showed typical symptoms. In the spring of 1940 the trial was repeated but, owing to the slow rate of reproduction the removal of newly-born larvae was continued for four days. In all, 47 larvae were transferred, of which three was the smallest number used per plant ; again no symptoms developed. In mid-March, 1941, and again in late April, similar experiments were carried out in which alate viviparous *P. fragariae* were substituted for the apterous mothers of the previous year. Seven and ten individuals, respectively, were transferred from two Severe Crinkle-affected Royal Sovereign plants to four *F. vesca* indicators, and 14 of the larvae were placed on four other indicators. None of the latter developed symptoms whereas all four plants carrying the alate mothers showed typical symptoms. It is concluded that larvae produced by *P. fragariae*, whether the latter are alatae or apterae, are not infective at birth. From the point of view of the field spread of viruses the results obtained with winged forms (alatae) are the more significant, since the initial

colonization of strawberry plants, not adjacent to others carrying apterae, is the result of larvae deposited by alatae.

2. *Virus transmission by larvae within 24 hours after birth.*

In September, 1939, a number of apterous, viviparous adults were placed on detached leaves from Severe Crinkle-affected Royal Sovereign plants and their larvae were removed at intervals of 24 hours to *F. vesca* indicators. Six plants were used and received a total of 34 larvae (three being the smallest number on any one plant) which were allowed to feed for 18 days before killing by fumigation. Four of the indicators became infected. In a repeat trial in the following spring 71 larvae were employed on six indicators, after they had fed on a Severe Crinkle-affected plant of Royal Sovereign during the first 24 hours after birth. Four of the indicators developed symptoms. These tests give more precision to Massee's (1942) statement that immature larvae are capable of acting as vectors, since Massee colonized individual plants with a mixed collection of larvae varying from the first to the fourth instar. There seems no reason to doubt, therefore, that the offspring of viviparous *P. fragariae* are able to take up some virus constituent of Crinkle and subsequently become infective at all stages of their development.

3. *Minimum number of aphides and period of feeding required for virus transmission.*

Since varying numbers of aphides are commonly used in experimental work it was necessary to ascertain the minimum aphis numbers and feeding time required for transmission. Table VII summarizes one such experiment the results of which have been confirmed many times.

TABLE VII.

Minimum time required to pick up a virus from Crinkle-affected plants.

F. vesca indicator.	No. of aphides applied.	Previous period on Crinkle-affected Royal Sovereign.	Symptoms on indicator.
1	1	2 mins.	none
2	3	5 ,,	none
3	3	15 ,,	none
4	3	15 ,,	none
5	3	1½ hours	typical Crinkle
6	3	1½ ,,	,, ,,
7	3	24 ,,	none
8	3	24 ,,	typical Crinkle

Under the conditions of the experiment, therefore, aphides were capable of picking up and transmitting a virus after spending 1½ hours on a Crinkle-affected strawberry plant. The experiment gave no information as to the possible existence of an obligate incubation period within the aphides, since they were allowed to feed on the indicators for three weeks, and transmission might have occurred at any time within this period. In a further experiment 10 aphides were fed for 2 hours, and another 10 for 4 hours, on a source of Crinkle in Royal Sovereign before being transferred singly to *F. vesca* indicators, on which they remained for only one hour. Five of the 10 plants in the first group and seven in the second group showed typical Crinkle symptoms, from which it is concluded that healthy plants in the field are liable to contract infection after, at most, one hour's feeding by a single aphis which had previously fed for not more than 2 hours on a Crinkle-affected plant. The trials also show that any incubation period within the insect (if such exists) must be of less than 3 hours' duration, and that the virus transmitted falls in the group of non-persistent ones.

4. *Seasonal infectivity of* P. fragariae *in the field.*

Massee (1935*a*, 1936, 1937) showed that *P. fragariae* could transmit the Yellow-edge virus, in the East Malling area, from infected to normal Royal Sovereigns under outdoor conditions

during the period March to August. During the earlier part of the present work, aphides of this species were collected in most months of the year from two crops of Royal Sovereign in which most of the plants showed either Crinkle of varying intensity or Mild Crinkle + Yellow-edge. No attempt was made to segregate insects according to the symptoms of the plant on which they were feeding. The collections were transferred to *F. vesca* plants kept out of doors to ensure environmental conditions appropriate to the time of year; and the results of the transfers are given in Table VIII.

Table VIII.

Infectivity of apterous P. fragariae *collected in the field.*

Date.	Number of plants colonized.	*F. vesca* indicator plants.		Notes.
		Average aphides per plant.	Number of plants infected.	
1940				
July 30th	2	1–2	0	3 larvae in all
July 31st	3	6	2	—
August 27th ..	2	8	2	—
August 30th ..	4	37	4	—
September 30th ..	4	30	2	2 plants died
October 16th ..	2	14	1	1 plant died
November 15th ..	4	20	3	1 plant died
December 10th ..	4	6	2	? 3rd plant infected
1941				
February 11th ..	4	4	4	collected after thaw of deep snow
April 8th	2	3	0	—
May 6th	2	2	1	—
June 7th	2	7	0	—
July 9th	2	22	1	—

Thus, aphides transmitted some strawberry virus during eight months of the year under North Wales conditions. No collection was made in January or in March, and there seems no reason to attach importance to the failure to secure transmission in April and June, 1941, since infectivity was demonstrated in the adjacent months; moreover, Massee (1936, 1937) obtained transmission in those two months. It is concluded that *P. fragariae*, except perhaps when completely immobilized by severe wintry conditions, can act as a vector at any time in the year. Many observations, however, have shown that the greatest spread occurs during the summer, as might be expected from the presence of alatae with conditions favourable for their flight as well as for the movement of apterae.

Possible sources of strawberry viruses in the field.

1. *Moribund outer leaves of Royal Sovereign.*

Most of the aphis transmission work described by the writers and, apparently by other workers, has been carried out with aphides collected from young, symptom-showing leaves, an exception being the cases described above of successful transmission with aphides collected during the winter months. Since, even in such cases, the insects might have obtained the virus from dormant crown buds, it seemed advisable to ascertain whether the virus in the oldest, moribund leaves was in an active form capable of causing infection. This was proved to be the case by feeding *P. fragariae* on 10 very old leaves on which symptoms could no longer be discerned with certainty although the plants from which they came were known to be diseased. The *F. vesca* indicators developed typical symptoms of the Crinkle type.

2. *Symptomless foliage of newly-infected plants.*

It was known, of course, that symptomless plants of carrier varieties such as Huxley and Oberschlesien are a source of danger to neighbouring sensitive varieties, and there is no difficulty in proving by aphis tests that such symptomless plants contain virus. Similarly, the early spring growth of foliage on diseased plants of Royal Sovereign is usually devoid of symptoms but readily yields an aphis-transmissible virus. It was not known, however, how soon a newly-infected, symptomless plant becomes a source of danger to healthy plants, although in the experiments to test virus inheritance it will be recalled that larvae from symptomless leaves on which infective aphides had been feeding for four days failed to pick up any virus. A plant of *F. vesca* usually develops definite symptoms in about 21 days after colonization with infective aphides, but this does not necessarily represent the time required for the plant itself to become infective. To test this, two young *F. vesca* plants, just beginning growth in mid-February, were each colonized with 25 Crinkle-carrying *P. fragariae* individuals which were allowed to feed for six hours before fumigation. At various later dates, non-viruliferous aphides were placed on the two plants for periods of 24 hours and then transferred to *F. vesca* indicators. Both the initially infected plants showed symptoms on the 21st day after colonization. The attempts at virus recovery were made on the 2nd, 9th, 20th, 26th and 42nd days after the first colonization with infective aphides. Of the indicator plants, those receiving aphides used on the 20th and 42nd days alone developed symptoms, i.e. virus was recovered from the *F. vesca* plants only from the time at which they were themselves developing symptoms.

In a repeat trial the recovery attempts were made on the first day of infection by using non-viruliferous aphides (marked with Indian ink) along with infective ones, and on the 3rd, 9th and 16th day following. When these aphides were transferred to *F. vesca* indicators after 24 hours feeding, no symptoms developed, although the original plants colonized with infective aphides showed typical symptoms in three weeks. Newly infected cultivated strawberry varieties have not been tested but, since virus can be recovered from old-established infection in *F. vesca* and Royal Sovereign plants at all seasons, whether symptoms are obvious or almost invisible, it would seem that the infectivity of recently infected leaves may be conditioned by the active concentration of the virus or by the establishment of stable relations with the cell contents.

3. *Other possible host plants of* P. fragariae *and strawberry viruses.*

When the present work began in 1938 there was no published information concerning the susceptibility to strawberry viruses of plants other than cultivated strawberry varieties ; but later, Harris and King (1940) reported successful grafts of Crinkle-infected plants to species of Potentilla and Godetia, though no symptoms were induced in the latter. Their attempts to transmit strawberry virus by mechanical inoculation to tobacco yielded, in one instance, " necrotic lesions of a very localized nature ". The species used by Harris and his co-workers (1937, 1942) have included *Fragaria vesca*, *F. chiloensis*, *F. indica* (=*Duchésnea indica*) and *F. virginiana* ; of these, the present writers have used only *F. vesca*.

The potential danger of a species of plant to cultivated strawberry crops depends upon whether both types of plants can be colonized and infected by a virus-carrying insect. Thus the fact that *P. fragariae* has not been found on the potato crop, and that none of the species of aphides common both to potato and strawberry appears to be capable of infecting strawberry, exonerates the potato as a likely source of strawberry degeneration; direct transference of typical potato viruses to strawberry, however, has not yet been attempted.

(*a*) *Colonization by* P. fragariae.—All available evidence points to *P. fragariae* as being the sole agent in the spread of strawberry viruses, so that for a plant species to act as a reservoir of strawberry viruses it should readily be colonizable by *P. fragariae*. In 1939, the writers infested a wide range of possible host plants to determine the potential risk of the aphis establishing itself on them in nature, and to ascertain the susceptibility to strawberry viruses of any that did become colonized. The following list is divided according to the ease with which the aphis became established :

A. On which the aphis readily lived and multiplied:
Potentilla anserina L. (Silverweed).

B. On which the aphis lived moderately well:

	Potentilla sterilis Garcke (Barren Strawberry).	Best.
	,, *comarum* Nestl. (Marsh Cinquefoil).	Best.
*	,, *fragiformis* Willd. ex Schlecht.	Best.
*	,, *Thurberi* A. Gray ex Lehm (from New Mexico).	Intermediate.
*	,, *nevadensis* Boiss (from Spain).	Poorest.

C. On which the aphis failed to live:
Achillea millefolium L. (Yarrow).
Agrimonia Eupatoria L. (Agrimony).
**Astilbe chinensis* Franch and Sav., var. *pumila*.
Brassica oleracea L. (Cabbage).
**Geum reptans* L.
Nicotiana tabacum L. (Tobacco).
Oxalis variabilis Lindl.
Potentilla erecta Hampe (Tormentil).
,, *reptans* L. (Cinquefoil).
Poterium sanguisorba L. (Burnet).
Plantago major L. (Plantain).
Rosa spinosissima L. (Burnet Rose).
Rubus fructicosus L. (Blackberry).
Rumex sp. (Dock).
Spirea ulmaria L. (Meadow-sweet).
Taraxacum dens-leonis Desf. (Dandelion).
Teucrium Scorodonia L. (Wood Sage).
Trifolium repens L. (White Clover).
Viola canina L. (Dog Violet).

*=non-indigenous species raised from purchased seed.

Hodson (1937), Massee *et al.* (1938) and Thomas and Jacob (1940), have all recorded *P. fragariae* on *Potentilla anserina*, whilst the last named writers noted also that *P. fragariae* can exist for some time on *Potentilla sterilis* when it is artificially infested.

(*b*) *Susceptibility of selected host species to strawberry viruses.* Following on the colonization results the species *Potentilla anserina*, *P. comarum*, *P. fragiformis*, *P. Thurberi* and *P. nevadensis* were selected for further study in 1939. Non-viruliferous apterae of *P. fragariae*, fed on these species for 9-10 days, failed to transmit any virus to *F. vesca* indicators and the initial health of the Potentillae could therefore be assumed. Aphides which had previously fed for nine days on a Severe Crinkle-affected Royal Sovereign were transferred twice, at an interval of 12 days, to the five species of Potentilla, on which they remained for a final period of four days. None of the plants developed symptoms, nor could any virus be recovered from them by means of *P. fragariae* transferred to *F. vesca*, in three tests made at different times of the year in 1939 and 1940. Only with *P. nevadensis* was there any doubt that the aphides fed well, and the fact that nine months elapsed between the attempts to infect the plants and the virus-recovery attempts shows that adequate time was given for a virus to become systemic. It was, however, possible that a virus had become localized in tissues unavailable to the aphis, particularly with the less palatable species into which the aphides might not thrust their stylets very deeply. Evidence of such a differential distribution of a virus has been presented for the Curly-Top disease of sugar beet, in which Bennett (1934) found that the vector leaf-hopper (*Eutettix tenellus*) rarely obtained the virus when feeding was restricted to certain parenchymatous tissues. The most that can be said in the present case is that any virus inaccessible to the insect vector is of academic rather than of practical interest.

Attempts to infect many of the plants by inoculating them with sap from Severe Crinkle-affected Royal Sovereign plants failed to give symptoms, and no virus was recovered either

by means of aphides or by grafting the two stolon-bearing species (*P. sterilis* and *P. erecta*) to *F. vesca*. Failure of mechanical transmission was presumably due to the fact that only non-infective sap was transferred (Bawden and Kleczkowski, 1945). Similarly, virus transmission from Severe Crinkle-affected Royal Sovereign to *P. anserina*, *P. reptans* and *P. erecta* by stolon-grafts failed through ineffective union.

(*c*) *Relation of common Rosaceous weeds to strawberry degeneration.* The woodland or wild strawberry (*Fragaria vesca*) is of special interest in relation to virus spread in cultivated strawberry plantations as it is so common and so sensitive to the viruses. The present writers have never found the strawberry aphis on plants of *F. vesca* under natural conditions in North Wales, thus confirming Massee *et al.* (1938) for south-east England. When, however, wild strawberry plants are grown between rows of cultivated ones they readily become colonized and infected by the aphis. Hence field headlands might possibly provide conditions favourable to colonization of *F. vesca* by the aphis, but the influence of such infested wild plants on the health of neighbouring strawberry beds would be negligible so long as carrier varieties of strawberry continue to be widely grown.

The only wild plant on which *P. fragariae* has been found under perfectly natural conditions is *Potentilla anserina* (Hodson, 1937 ; Massee *et al.*, 1938 ; and Thomas and Jacob, 1940) ; and further work to confirm the previous negative results with this plant seemed desirable. Another common stoloniferous weed of the same family, the barren strawberry (*Potentilla sterilis*), was included in the trials although there is no record of *P. fragariae* on it. Pairs of plants of each species were colonized with non-viruliferous aphides which, nine days later, were transferred to *F. vesca* indicators and left for a further nine days. The numbers placed on the indicators ranged from 3 to 28, but the indicators remained symptomless showing that the two *Potentillas* were initially free from strawberry viruses. They were next colonized twice with large numbers of Crinkle-fed aphides, but they developed no symptoms during four months, and no virus was recovered from them by means of *P. fragariae*.

In a repeat experiment in 1941, plants of the same two species were heavily colonized, some with Crinkle-fed and others with Yellow-edge infected aphides, and the plants were afterwards stolon-grafted by inarching to *F. vesca*. Successful unions were obtained with both species, but whilst no virus was recovered from *P. anserina*, most of the *P. sterilis* plants induced typical virus symptoms in the indicators. The tests with *P. anserina* were repeated in 1942 by both grafting and aphis-transmission for recovery of virus, with the same negative results. In further efforts with *P. sterilis* to recover virus by means of the aphis, and so to confirm the positive evidence obtained earlier, by grafting, that the plant could act as a symptomless carrier, successful transmission was obtained, probably because the work was carried out at a time (early spring under glass) very favourable both for plant and aphis activity. The conclusion is reached that, while *P. anserina* is immune from strawberry viruses, *P. sterilis* can act as a symptomless carrier of one or more viruses present in Crinkle and Yellow-edge. On the other hand, the consistently negative results obtained by grafting untreated plants of this species to *F. vesca* suggest that *P. sterilis* is not found in nature infected with a virus transmissible to strawberry ; and so long as it is avoided by the aphis, *P. fragariae*, it is not likely to become so.

DISCUSSION.

Given foci of severe virus diseases in a strawberry plantation, the rate at which degeneration sets in is directly related to the population of *Pentatrichopus fragariae*. Almost certainly this aphis is the sole means by which infection spreads in the strawberry crop, for the only other known vector (*P. tetrarhodus*) is restricted to the genus Rosa and has not been recorded on strawberry. Again, all available evidence tends to prove that, apart from cultivated strawberry varieties, there is no other source of strawberry viruses. Many of the most probable reservoirs of disease have been tested and none has yielded a virus transmissible to strawberry, or has proved susceptible except *Fragaria vesca* and *Potentilla sterilis*, neither of which is normally a host of the aphis.

Control therefore must be based on eradicating the aphis and/or the disease foci. Considerable success has been attained in the control of the aphis by using a nicotine vaporizer (Massee and Greenslade, 1941*b*), and a modified form of this should soon be available to growers

at small cost. Fumigation, by itself, is unlikely to be sufficient, because a single aphis feeding for two hours on a source of infection is capable of spreading a virus after no more than one hour's sojourn on a healthy plant. The eradication of disease foci is also a difficult problem. Vigorous runners can be raised from healthy plants grown in isolation in pastoral areas in North Wales, and used to build up the healthiest possible commercial stocks. But so long as such runners are planted near infected, older stocks, their health will not be maintained in years of high aphis prevalence, in spite of nicotine treatment.

The rapidity with which commercial stocks have degenerated between the two world wars is related to the widespread introduction of new varieties, some of which are carriers of viruses. It is not difficult to obtain vigorous, and only mildly infected stocks of varieties such as Royal Sovereign in areas remote from commercial plantations ; indeed the existing virus-free stocks of this variety were discovered in pastoral Co. Mayo, Ireland (Harris and King, 1940). The breeding of commercially acceptable resistant or immune varieties is doubtless the ultimate solution, but meanwhile, the consistent fumigation of plantations and the up-grading of runner-stocks by the present system of certification by the Ministry of Agriculture provide the most hopeful means of rehabilitating the strawberry industry.

ACKNOWLEDGMENTS.

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SUMMARY.

Degeneration in commercial strawberry plantations in North Wales has been studied ; the general aspects of the problem are discussed but the etiology of the strawberry virus diseases themselves will be dealt with elsewhere.

The percentage of the more serious categories of degeneration (i.e. severe forms of Dwarfing, Yellow-edge and Crinkle) is shown to be closely related to the intensity of the population of the strawberry aphis *Pentatrichopus fragariae* (Theob.).

In seasons of low aphis population it is easy to select vigorous, almost symptomless, runners from maiden (first-year) beds for propagation, but in seasons of high infestation the beds, irrespective of age, become overwhelmed by disease, and such selection is impossible. Vigorous stocks have shown extreme degeneracy within nine months of their introduction.

Tests of aphis species commonly found on strawberry showed that *P. fragariae*, alone, could act as a vector ; *P. tetrarhodus*, though equally efficient, has not yet been recorded on strawberry ; *P. potentillae* is restricted to silverweed (*Potentilla anserina*) and is not a strawberry virus vector. The nomenclature of the strawberry aphis is discussed.

P. fragariae does not " inherit " virus infectivity from a viruliferous, viviparous parent, but is capable of picking up and transmitting a virus from Crinkle-affected plants within 24 hours after birth. Transmission is possible by a single individual and at all seasons of the year. Less than two hours feeding on an infected plant, followed by one hour on an indicator plant, may suffice to transmit a strawberry virus to the latter.

The possible sources of infection are considered. It is shown that virus in symptomless carrier varieties and in moribund leaves of infected Royal Sovereign plants remains active, but that newly infected leaves of the wild strawberry (*Fragaria vesca*) do not become infective until symptoms begin to appear in them. The possibility of wild *F. vesca* serving as a natural reservoir of strawberry viruses is remote. Silverweed (*Potentilla anserina*) is immune from strawberry viruses, whilst barren strawberry (*Potentilla sterilis*) becomes a symptomless carrier when artificially infected.

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NETTLEHEAD DISEASE OF THE HOP (*HUMULUS LUPULUS*)

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This disease was first described by Percival (1895) who ascribed it to attacks by the eelworm *Heterodera Schachtii*, which was found on the fine roots of affected plants; but Percival gave no experimental evidence that the invasion of the roots by the eelworm gave rise to the symptoms seen above ground.

Duffield (1925) found that there were no significant differences between the eelworm populations on the roots of healthy plants and plants affected with Nettlehead or Mosaic disease (then called "False Nettlehead"), and thus concluded that these diseases were not caused primarily by *H. Schachtii*.

Experiments by Salmon and Ware (1930) and Ware (1939) gave some evidence that Nettlehead was graft-transmissible, but the results were inconclusive. However, the disease was included by Smith (1937) and other authors in their lists of virus diseases of plants.

The present investigation was undertaken to obtain further evidence on the transmission of Nettlehead by grafting and also to study the incidence of the disease in commercial plantations.

Symptoms.

Diseased plants can first be distinguished in April and May, shortly after the bines (stems) begin to grow. The affected bines do not twist in the normal fashion but are conspicuously rigid and have shortened internodes. The leaves stand out stiffly and their edges are curled upwards. The number of affected bines and the ease with which symptoms can be distinguished vary greatly from plant to plant. Sometimes only one affected bine can be seen on an otherwise apparently healthy plant, on other plants there may be several bines showing obvious symptoms; on others, again, the bines may be very few in number, stunted and bear malformed leaves. Another disorder of hops, Split Leaf Blotch, also causes this stunting but does not cause leaf curl.

In early May, when the bines are thinned to six or eight per plant and trained up the strings, the contrast between diseased and healthy plants becomes less obvious. As the bines grow, however, the leaf curl symptoms may again be seen; in addition, the bines lose their climbing power and fall away from the strings giving a characteristic dwarfed appearance to the plants (Fig. 1, Plate I). At this time, further symptoms appear. The bines become very brittle and of a dull yellowish-brown colour; also the basal lobes of the newly formed leaves are small or absent, the leaves then resembling those of the nettle. Their lower surfaces are greyish in colour and the veins are prominent and have short translucent portions. The bines eventually die back from the tips, the leaves often show a very striking vein banding and then turn yellow and die. On badly diseased plants the hop cones are few and small, but on less severely affected plants the crop may be almost normal although the bracts and bracteoles of the cones are usually distorted.

The disease does not kill the plant but renders it weaker year by year. The centre of the stock becomes rotted and the new buds are confined to a thin rim of living tissue.

Symptoms of the disease become less obvious on plants growing at high temperatures. This is due to the fact that the new growth produced under these conditions appears normal, while the older leaves may have fallen off or been removed in the cultural processes of "thinning" and "stripping". Thus, severely affected plants appear healthy after being grown in a warm glasshouse for a few weeks, and a similar phenomenon can be observed in the field during periods of high temperature. This is often clearly shown on the lateral branches which may bear both curled and normal leaves. (Fig. 2, Plate I.)

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GRAFTING EXPERIMENTS.

In continuation of the work of Salmon and Ware (loc. cit.) a series of experiments was made to determine whether Nettlehead was graft-transmissible.

(a) *Material.*

Two types of diseased material were used, viz. cuttings from infected bines in commercial plantations and complete, infected plants from commercial plantations, the material being collected in the autumn of 1939. Healthy cuttings to provide the indicator and control plants were obtained at the same time from commercial plantations previously inspected to ensure complete freedom from Nettlehead. As the plants thus obtained were not of recent clonal origin and might therefore show variations in reaction to infection, the control and indicator plants for each graft were grown from cuttings taken from the same parent plant. The variety used throughout was Fuggle.

(b) *Methods.*

The method of inarching, first suggested for use with hops by Salmon and Ware (1925) was used in all the experiments. A procedure evolved by Harris (Harris and King, 1942) was employed, in which oblique opposing cuts were made in the two bines to be inarched when these were from 9 in. to 24 in. long (i.e. in April-May, 1940); the tongues thus formed were interlocked and the graft bound with crepe rubber. Neither bine was severed from its rootstock.

The graft units were of two types, simple and multiple. The former consisted of one healthy indicator inarched to a single small infector plant, and the latter of three to six healthy indicators inarched to a single large infector plant. Ungrafted control plants were grown adjacent to the grafted indicators and were thus under similar environmental conditions.

The experiments were conducted both in a glasshouse and in the field. In the glasshouse the plants were sprayed regularly with 0·05 per cent. nicotine to control aphis, and with water from a pressure hose to check red spider. The plants grown in the field were not sprayed.

(c) *Experimental results.*

Union of the grafts took place in eight days in the glasshouse and in twelve days out of doors. Of the ninety-eight grafts made, eighty were successful. Symptoms of Nettlehead were seen in September, 1940, on two only of the plants grown in the field. Neither the infector nor the indicator plants in the glasshouse showed any clearly recognizable symptoms in 1940. All the experimental plants were therefore planted out of doors early in April, 1941 and kept under observation throughout the growing season. The observations are summarized in Tables I and II.

TABLE I.

Grafts made in the glasshouse.

Graft units.	No. of successful grafts.	No. of transmissions.	No. of controls.	No. of controls infected.
Multiple	6	6	5	0
,, ...	6	6	7	0
Simple	17	15	19	0
Totals	29	27	31	0

These Tables demonstrate that 89 per cent. of the grafted plants became infected. None of the control plants in the glasshouse contracted the disease, but 12 per cent. of those in the field showed symptoms in 1941, presumably as a result of natural infection during the course of the experiment. It may thus be concluded that Nettlehead is graft-transmissible.

As described, only two of the fifty-one plants grafted out of doors in 1940, and none of the controls, showed symptoms in that season. From May to September, 1941, forty-two grafted plants and eight controls showed symptoms. The remaining seven grafted plants might

TABLE II.

Grafts made in the field.

Graft units.	No. of successful grafts.	No. of transmissions.	No. of controls.	No. of controls infected.
Multiple	5	4	4	1
,, ...	4	2	4	1
,, ...	3	3	5	1
,, ...	3	3	5	0
,, ...	4	4	5	0
,, ...	4	2	5	1
,, ...	4	4	5	0
,, ...	5	4	5	2
,, ...	2	2	6	0
,, ...	2	2	3	1
,, ...	3	3	5	1
,, ...	4	3	4	0
Simple	8	8	10	0
Totals	51	44	66	8

possibly have developed symptoms in 1942 but this could not be tested owing to likelihood of natural infection occurring in the interim.

The control plants may be considered as analagous to those growing in commercial hop fields where a similar time lag presumably occurs between infection and symptom expression.

INCIDENCE AND SPREAD OF NETTLEHEAD IN COMMERCIAL PLANTATIONS.

Nettlehead was observed on the commercial varieties: Fuggle, Tutsham, Cobb, Mathon, Early Bird and Bramling, and on the new Wye seedling variety, Brewer's Gold. It was particularly prevalent on the variety Fuggle (which constitutes over 75 per cent. of the total hop acreage in England) and was most widespread in the Weald of Kent and Sussex and in Herefordshire, where this variety is most commonly grown. Individual outbreaks varied from 0·2 to 50 per cent. of the plants, and of the several hundred fields inspected only very few were found to be completely free from the disease. It was obvious that Nettlehead was causing a considerable total loss of crop and it appeared in this respect to be the most serious disease of hops. Observations made since 1940 have shown that the disease is slowly becoming more widespread, a process that appears to have been going on since Nettlehead was first reported fifty years ago.

Observations on cuttings from infected bines have shown that these invariably produce plants infected with Nettlehead, and the distribution of such infected planting stock is the main means by which the disease is spread from farm to farm.

The rate of spread from infected to healthy plants in the hop fields is not so great as with many other virus diseases and varies greatly in different localities and seasons. It is quite common, however, for the number of affected plants to be doubled each year; and the cumulative effect of this increase is considerable, hops intended to stand for forty years often having to be grubbed after ten years growth.

Maps of disease outbreaks were made in fields planted on two systems. In one, the "Square Plant" system, in which the hops are planted 6 ft. by 6 ft., cultivation is possible in two directions at right angles, and the bines of each plant are in contact with those of the immediately adjacent plants in each direction. In the other, the "Worcester" system, planted at 7 ft. by $3\frac{1}{2}$ ft., the cultivators can move only along the alleys, and the bines of each plant are in contact only with those of adjacent plants in the same row.

Figs. 3 and 4 illustrate maps of one field of each type, made in 1939 and 1940. It will be noted that in the square-plant field the disease has spread in all directions, but in the Worcester-plant field the preponderance of spread is along the rows, although isolated new infections do occur elsewhere. There is a similarity between these observations and those made on the *Verticillium* wilt of hops (Keyworth, 1942) which is spread by the transport of infected plant debris

and soil on the cultivators. Percival (loc. cit.) stated that Nettlehead is spread by the cultivators but gave no proof of this.

FIG. 3.

(a) (b)

Nettlehead incidence in "Square Plant" Field.

× = Nettlehead plant.

(a) Incidence in 1939.
(b) Incidence in 1939 and 1940 combined to demonstrate spread.

The following experiment was made to test whether infected debris could transmit Nettlehead :—

One quarter-bushel of each of the following materials was dug into plots in which young hops were growing : (a) chopped bine from Nettlehead plants, (b) chopped rootstocks and roots from Nettlehead plants, (c) soil from beneath Nettlehead plants, (d) uncontaminated soil. Each plot contained five plants and each treatment was replicated four times. The plants were grown for three seasons.

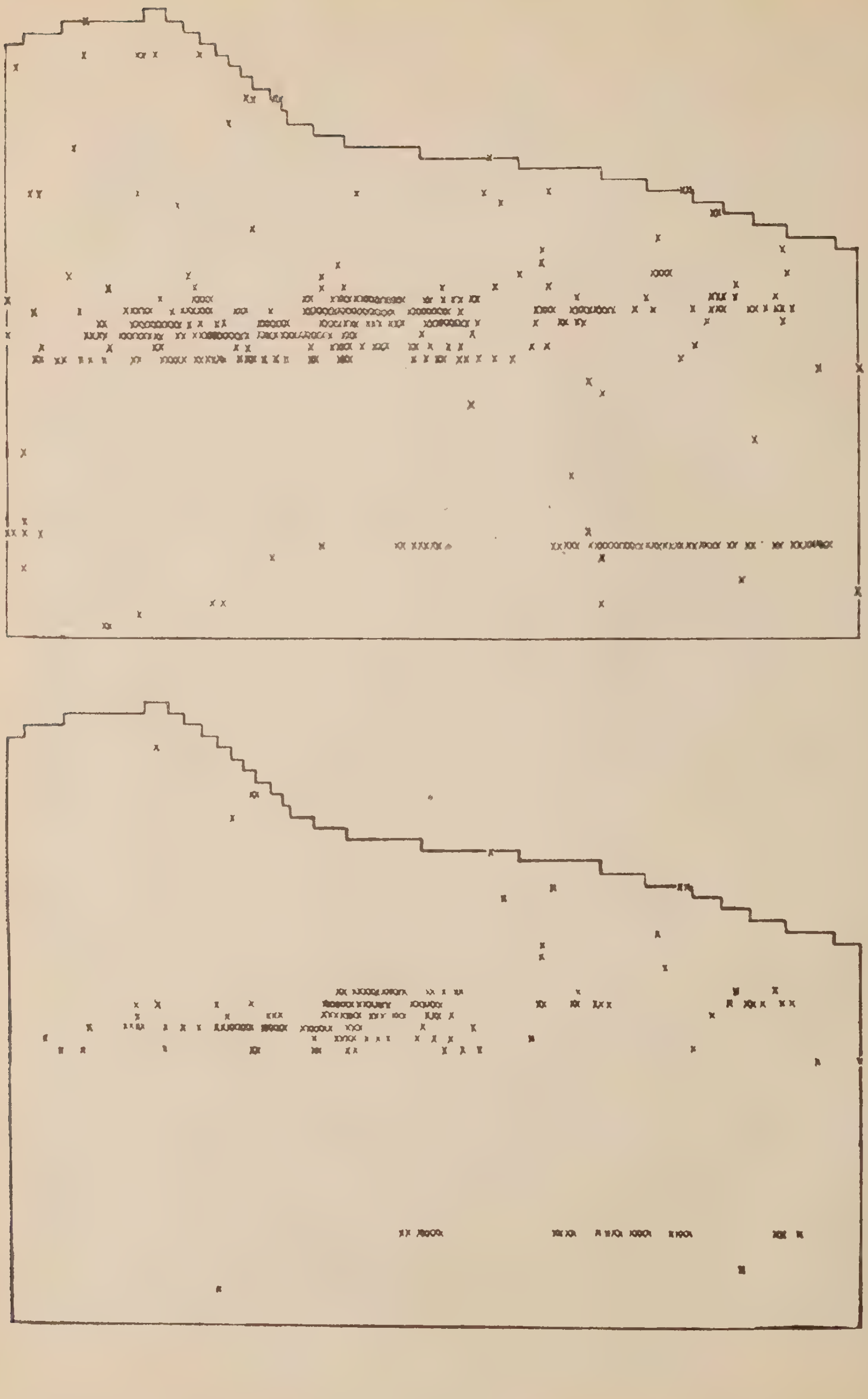

FIG. 4.

Nettlehead incidence in "Worcester Plant" Field.

× = Nettlehead plant.

(*a*) Incidence in 1939.
(*b*) Incidence in 1939 and 1940 combined to demonstrate spread.

PLATE I

Fig. 1.
Hop plant affected with Nettlehead.

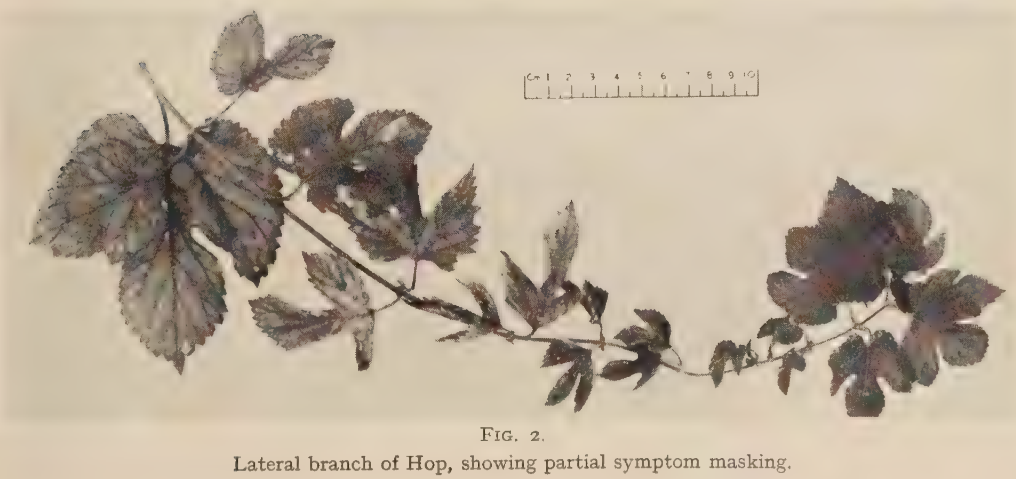

Fig. 2.
Lateral branch of Hop, showing partial symptom masking.

[*face p.* 138

No Nettlehead symptoms appeared on any plant and it was thus concluded that the disease had not been transmitted by any of the treatments.

There is thus no direct evidence that Nettlehead is transmitted by the transport of infected debris. The directional spread of the disease in Worcester Plant fields may be related to bine contact along the rows and consequent ease of movement of an insect vector. This cannot be confirmed until information is available on the identity of the vector.

A feature of this disease is the large number of outbreaks having an apparent connection with local soil conditions or with nearby hedgerows or trees. Duffield (loc. cit.) reported that Nettlehead often appeared after about three years on ploughed pasture land and that in some cases the outbreak first appeared next to a hedgerow or large trees. Duffield's observations are supported both by the authors' own observations and by reports received by them from growers. One outbreak in Herefordshire clearly illustrated both the incidence of the disease at the edge of the field near a hedge and its recurrence in the same place after a large portion of the field had been completely grubbed and replanted.

CONTROL MEASURES.

Only two measures can at present be advised, viz. the roguing out of infected plants and the use of healthy planting stock.

Observations have shown that although careful roguing will greatly check the disease, this measure will rarely eradicate it entirely. This seems to be due to two factors, symptom masking and the time lag between infection and symptom expression. Growers are therefore now advised to start roguing their fields as soon as symptoms can be detected and to continue throughout the season. In order to counteract the time lag in symptom expression the removal of all plants next to those showing the disease is also advisable, but this is obviously practicable only when the outbreak is small.

Experience at East Malling has shown that by planting Nettlehead-free stock not less than one-quarter mile from neighbouring hops a healthy stand can be maintained for many years.

SUMMARY.

Grafting experiments with hop plants (var. Fuggle) affected with Nettlehead showed the disease to be graft-transmissible. There was usually a time interval of nine to twelve months between grafting and symptom expression. Symptoms were suppressed during periods of warm weather and when infected plants were grown in a warm glasshouse. Observations in commercial plantations showed that the disease spread along the rows when these were "close-planted" and that disease outbreaks often occurred at the edges of fields near hedgerows.

Control measures suggested are the roguing out of affected plants and the use of healthy stock for propagation.

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THE BIOLOGY OF THE APPLE BLOSSOM WEEVIL, *ANTHONOMUS POMORUM* L.

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INTRODUCTION.

For many years *Anthonomus pomorum* L. has been considered an important pest of apple. This is undoubtedly so in orchards where favourable hibernating quarters are situated nearby in the form of woods, banks, thick hedgerows or dykes, and also in cordon plantations. Elsewhere the insect may be beneficial by thinning the blossom, except in off years when its unregulated activities cause severe crop losses.

Since Miles (1923) worked out the life history of this weevil in detail varying success has attended the efforts of many workers who have endeavoured to find a satisfactory control. More recently it became apparent that further biological studies were necessary to provide critical data on the times of emergence of adults from hibernation and egg laying. This investigation was begun in 1941 by Greenslade (1945) and was taken over by the present writer early in 1943. The results have added considerably to our knowledge of the habits of this weevil and, whilst emphasis is laid on those parts of the life cycle which have received most detailed attention, many previously known facts are recapitulated in order to present a coherent story.

While a large part of the work described here has been carried out at East Malling, observations have also been made in Essex during the past two seasons by the author's participation in investigations concerning this pest, initiated in December, 1943, through the collaboration of the Agricultural Research Council, the Pettar Society of Winter Wash Manufacturers and the Associated Fruit Growers of Essex, Ltd. Facilities provided by this joint arrangement have materially assisted in the life history studies here presented by enabling information on the habits of this pest to be secured under conditions prevailing in another important fruit-growing area. They have also enabled valuable experiments in the control of the weevil to be made, the results of which are presented in the paper on p. 162.

LIFE HISTORY.

Material and Methods.

Most of the observations have been made at East Malling, on the variety Lane's Prince Albert. The main plot (C.3) consisted of bush trees on a variety of rootstocks, planted in 1927, and interplanted in both directions with pears and half-standard apples. From this plot a square block containing 81 Lane's was chosen for detailed records.

The adult population was assessed by tapping all the outer branches of a tree and catching the weevils thus dislodged on a beating tray. After counting, the weevils were shaken to the ground beneath the tree in order to disturb the population balance as little as possible. Each day's record consisted of the total from nine trees selected by the " knight's move " method, always starting in the west row. Thus records from the same trees were made only once in ten times. Counts were made every other day in 1943, and at three-day intervals in 1944 and 1945.

Information on the egg, larval, pupal and early adult stages was obtained by random selection of four fruit buds from the north, east, south and west sides of each tree on the day it was tapped. The 144 buds collected were inspected under a binocular microscope and dissected if punctures were present. As the fruit buds developed into blossom trusses the truss was taken as the unit and not a blossom bud, in order to keep the sample uniform. Sampling showed there were 5·5 blossom buds to a truss, so the routine sample contained approximately 800 blossom buds.

During 1944 and 1945 similar records were taken in Essex by workers at the Field Laboratory, Great Braxted. Different orchards had to be used each year, but the variety remained constant, viz. Cox's Orange Pippin.

Records taken in 1943, primarily to gain information on the period over which weevils emerged from hibernation, served also to demonstrate the efficiency of the tapping method ; it was found very sensitive as shown by Fig. 1. Further confirmation of the efficiency of this method was obtained in 1944 and 1945, when the adult population was sampled independently on another plot of Lane's at East Malling (Fig. 2).

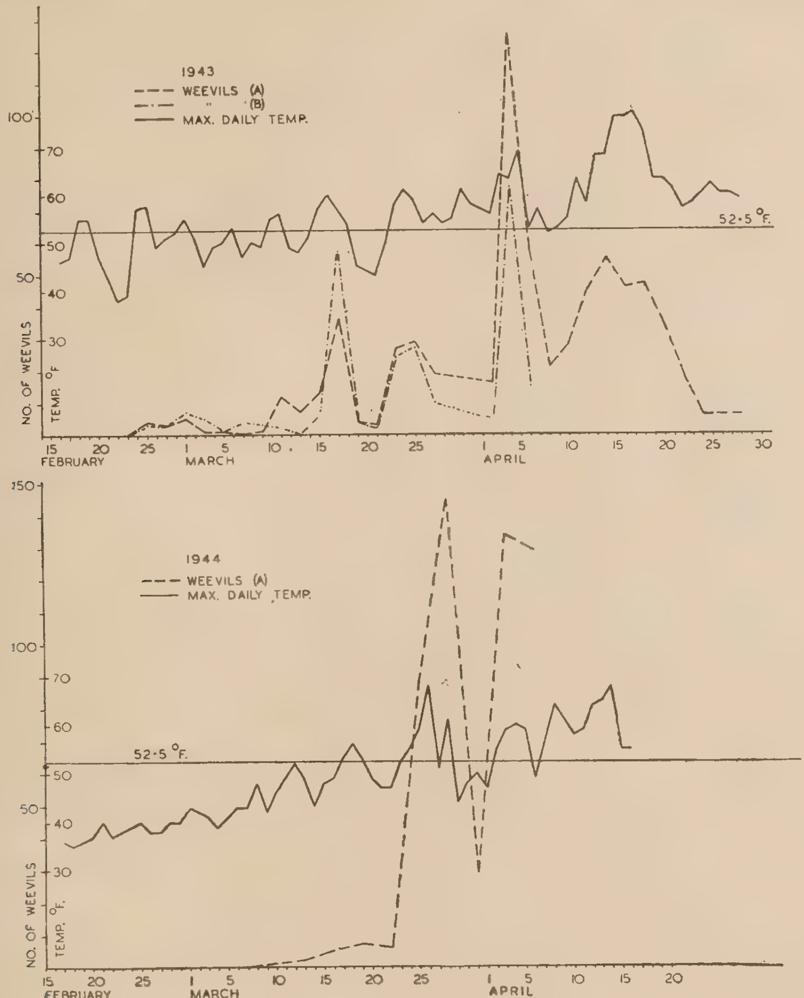

Fig. 1.

Relationship between weevils emerging from hibernation and maximum, daily, screen temperature.

Although tapping is a simple and probably the only practical method of assessing adult populations it has inherent limitations. For example, records cannot be taken when a strong wind is blowing, nor are the results accurate when the trees are wet. Also, the numbers recorded consist of those weevils living on the perimeter branches, unless the trees are small. When the weather is cold, especially during the early part of the season, it has been observed that many individuals shelter under loose bark and seldom get dislodged. Hence results can be considered representative except during periods of unfavourable weather.

Emergence of weevils from hibernation.

Single weevils can be found moving about on apple trees throughout the year, but the urge to leave hibernating quarters and start feeding does not occur until late February or early March. The individuals first encountered have usually overwintered under the loose bark of the trees on which they are found or in similar situations where slight rises in temperature are most perceptible ; later they are joined by others arriving from the hedgerows and woods. Fig. 1 shows how greatly temperature influences their activities at this time of year ; the graphs illustrate the numbers of weevils tapped from a row of headland trees (A) and a portion of a double row growing in isolation (B). All the weevils were removed after counting so that each subsequent total represents new arrivals over a period of two days. As these trees were small and every branch was tapped the numbers may be considered to represent total populations.

The date at which weevils begin to emerge from hibernation depends on the prevailing weather conditions. In 1944 a cold spell lasting until mid-March delayed emergence of the first weevil a fortnight as compared with 1943, when the corresponding period was much warmer. Similarly, in 1945, an exceptionally early season advanced the date nearly two weeks (Fig. 2).

From Fig. 1 it will be seen that when weevils once began to move a few came out daily, but whenever the temperature, measured in the screen, rose to between 50° F. and 55° F. the numbers greatly increased. The data available are insufficient to give a critical temperature, but for purposes of comparison an arbitrary figure of 52·5° F. has been marked on the graphs ; this is in very close agreement with the findings of Kaiser (1943) who states that in the Darmstadt area of Germany migration to the trees does not occur unless the maximum daily temperature reaches 50-52° F. In both 1943 and 1944 there occurred a short spell with high temperatures at the end of March or early April when a large proportion of the hibernating population returned to the trees. Up to, and including, this peak period samples from each total were dissected and, with few exceptions, no food was found in the gut, indicating that the weevils came direct from hibernation. Each year a few cooler days then occurred, followed by warmer ones, with a corresponding reduction and increase, respectively, in the number of weevils collected. At this stage dissection showed that many had already fed, proving that most of them came from other trees and not direct from hibernation. Thus, by early April the majority were on the trees, and those obtained subsequently mostly represented movement within the plots, of weevils which had left their hibernating quarters at an earlier date. The decrease observed in 1943 towards the end of April was due to natural mortality ; counts were discontinued in 1944 immediately dissection showed that a large proportion of the weevils had food in the gut.

The season in 1945 was a very early one and the peak emergence period coincided with a hot spell in mid-March. Each year this period was vividly illustrated at East Malling by the number of weevils emerging from cracks in the chestnut posts supporting the fences. From an occasional individual here and there, in the early stages, the numbers suddenly increased to three or four on each post top, and in the hot sunshine they could be watched taking wing in search of apple trees.

If Fig. 2, representing samples of the total population, is now studied it will be seen that at East Malling the population continued to build itself up until the second week in April, in 1943 and 1944, whilst in 1945 it reached a maximum during the latter half of March. For a fortnight the population remained high then began to decline, due to natural mortality. Probably males are shorter lived than females, for in laboratory egg-laying trials the former tended to die off first. The population continued to fall until newly emerged adults left the capped blossoms. Greenslade (1945) found no weevils at all on the trees for a short period prior to the arrival of the new generation, but during the past three years small numbers have always been present.

The figures obtained from Essex agree well with those from East Malling. One marked difference, however, is the rapidity with which the population became built up in 1944. A possible explanation lies in the fact that the plot on which records were made adjoined a bank where many weevils hibernated.

Up to the time of peak emergence females are more numerous and comprise 60 per cent. of the total population. Afterwards the sexes emerge in equal numbers, so that there is always

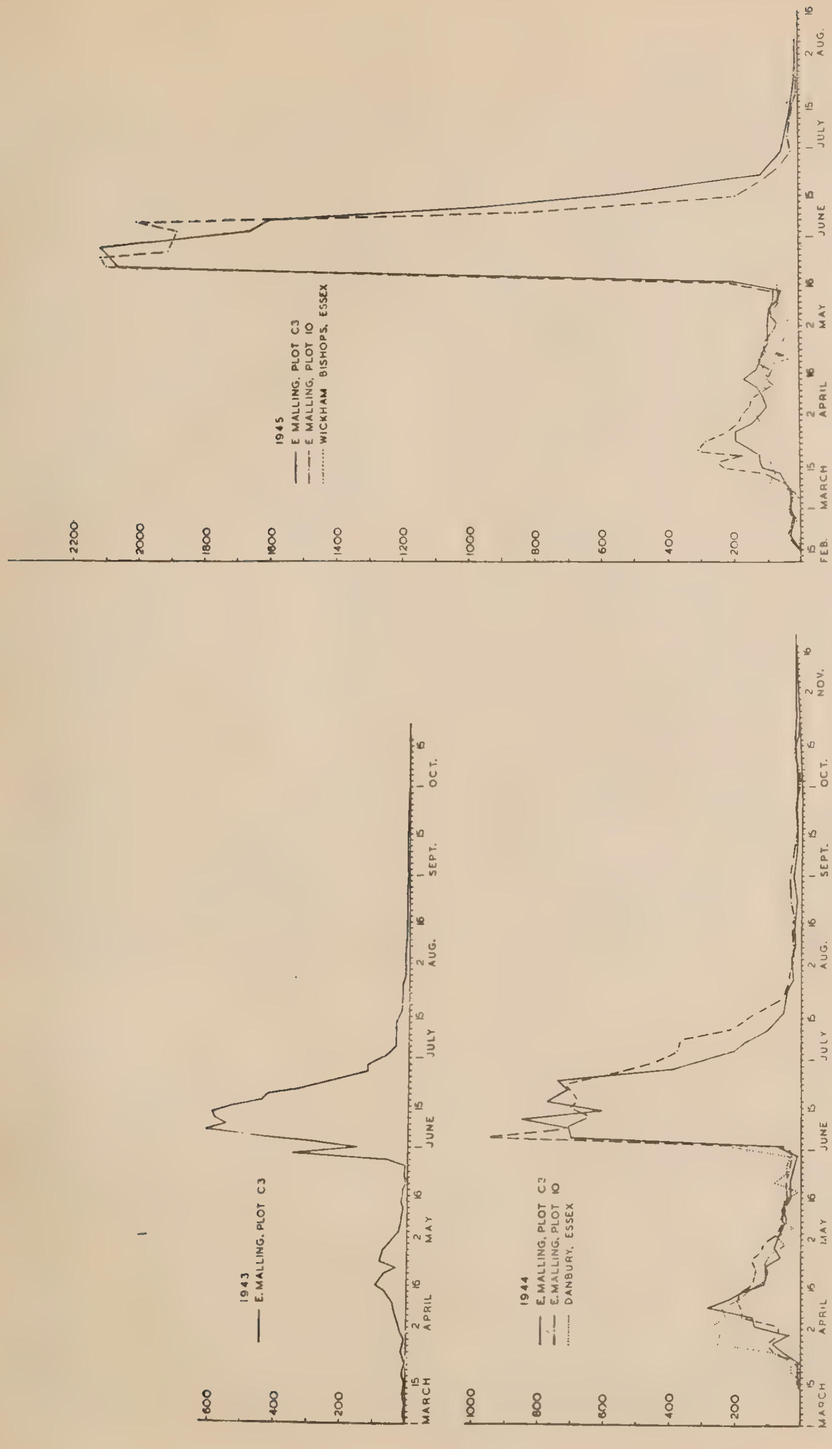

FIG. 2.

Variation in weevil populations on apple trees during the active period,

a preponderance of females, amounting to between 5 and 10 per cent. of the total, when the population is at its height.

Feeding habits and mating.

Buds have not always begun to open when the first weevils come out of hibernation and these wait, sometimes a week, until the outer scales separate before beginning to feed; they then pierce a hole through the inner bud scales and the rudimentary rosette leaves, or bore downwards from the tip to feed on the developing fruit buds. At this stage, if pruning is in progress, food is also obtained from the shoots. Only fresh cuts are attractive, the weevil standing on the cut end and boring with its rostrum into the phloem. Later, food is obtained exclusively from the blossom buds; a puncture is made through the side, and the stamens and stigma partially or completely eaten. Once the buds have burst, weevils begin feeding as soon as they reach the trees. Feeding punctures are much larger in diameter than those made during the egg-laying process and, with a little practice, the two types can easily be distinguished. From the green cluster stage onwards food is also obtained from the young ovary, a hole being bored into it from the side and the centre excavated as with the buds.

Weather conditions greatly influence the activities of the weevils. Feeding takes place during warm, calm periods, the remainder of the time being spent under shelter or by clinging closely to a spur or small branch. The most favoured situations are against spurs, where the irregularities of surface due to pruning provide some shelter and a firm foothold, or in crotches formed at the junction of two small branches. When the temperature rises above 50° F. weevils show considerable activity, wandering from branch to branch and flying from tree to tree. In the paper on p. 162, on control measures, this movement is shown to be of great importance; for, providing a persistent, contact insecticide is used there is no necessity to hit every weevil at the time of application. Those missed, and others arriving on the trees within the period during which the insecticide remains toxic, are almost certain to come in contact with the deposit on the branches in the course of their travels. Furthermore, this mobility of the weevil during feeding, mating and egg-laying makes it unnecessary to insist on a complete cover of the branches with spray or dust, as is essential when operations are directed against static pests such as scale insects or the eggs of aphides, etc.

Males are desirous to mate almost as soon as they have fed and pairs can be seen about on the trees from an early date, especially during the resting periods. The male clings to the female in a characteristic attitude, with his body inclined upward at a slight angle and the rostrum held straight out in line with the body. The female tolerates this attention but gives no encouragement, for on close inspection it is noticed that her abdomen is kept well tucked under the elytra. Miles (1923) and Greenslade (1945) suggest that mating takes place at an early date, but the present writer considers that only a few days elapse between mating and egg laying. Perhaps the preliminary attempts to mate have been misinterpreted in the past.

The egg-laying period.

The thin-shelled, translucent, oval eggs. averaging 0·7 by 0·5 mm., are laid in the young blossom buds. With her rostrum the female bores a small hole in the side of a bud and excavates a slight groove in an anther lobe; she then reverses her position and with the ovipositor deposits an egg in the groove. These actions were described in detail by Miles (1923). A sound bud is always chosen to receive the egg and more than one is rarely found in a bud. Though the small egg-laying puncture is easily distinguished from the larger hole made when feeding, there are often similar punctures in buds that contain no eggs; thus population studies involve the dissection of any bud which possesses the characteristic puncture. The methods by which the buds were sampled have already been described.

In the field, egg-laying begins when the fruit buds reach the bud burst stage, i.e. as soon as the tips of the rosette leaves begin to protrude above the apex of the bud. At first the puncture has to be made through the rosette leaves as well as through the side of the blossom bud, but soon the former unfold, leaving the cluster of blossom buds free. The time when egg-laying begins is of vital importance in the correct timing of sprays or dusts used to control this pest. That it should coincide with a well-known stage in bud development is a great

advantage, for this enables advice to be given without reference to actual dates, which of necessity vary from year to year according to the prevailing weather conditions.

Fig. 3 shows diagrammatically that part of the life history which occurs within the bud, each column representing the combined totals of all stages present in a sample. During the years under review eggs were first found on observation plots on March 31st, 1943, April 3rd, 1944, and March 17th, 1945, in Kent ; and on April 3rd, 1944, and March 19th, 1945, in Essex. Once egg-laying has begun it continues fairly regularly for about three weeks, then falls off rapidly. There was no suggestion of the majority of eggs being laid within a few days, as recorded by Greenslade (1945), nor did the weather appear to exert any great influence.

At first eggs are found in only one or two buds of a truss, but as the number of weevils

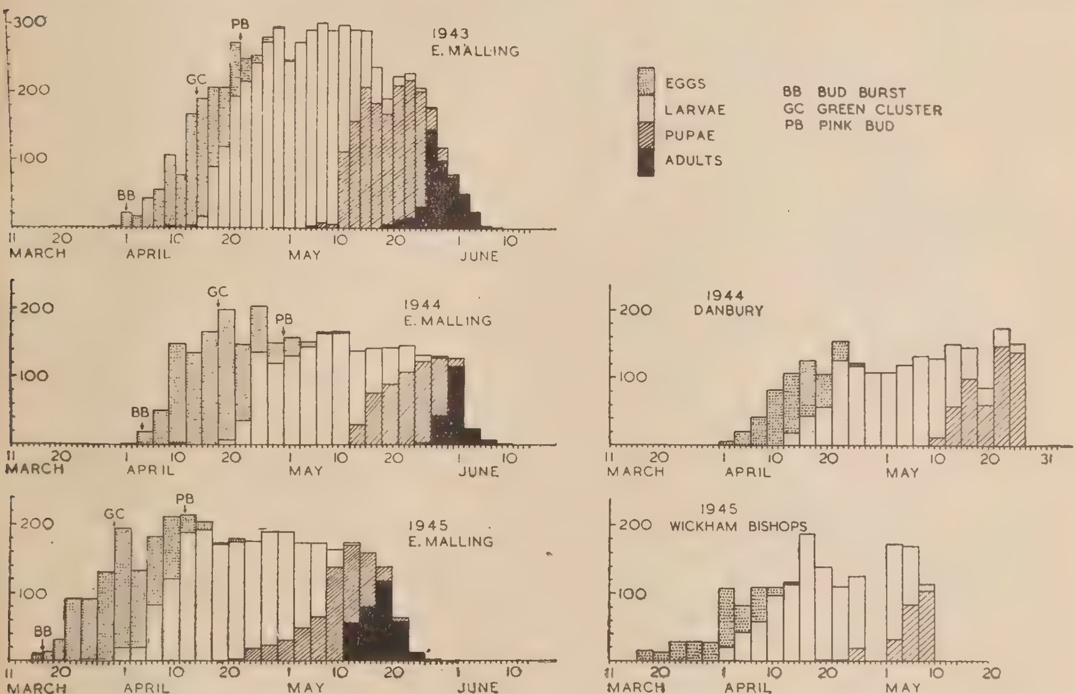

FIG. 3.
Life history of the weevil within the blossom bud.

increases a greater proportion of buds becomes attacked ; when the infestation is severe, every bud in a truss may contain an egg. The weevils show no preference for trusses in any particular position on the tree, nor are they attracted to one side more than another. They do, however, lay a far smaller percentage of their eggs in the King bud than in any of the others. From a series of samples it was found that only 8 per cent. of the King buds possessed eggs whilst the figure was 30 per cent. for a bud in any other position. This is unfortunate, for it is the opinion of pomologists that the King bud is the least desirable to be retained for fruit production.

Number of eggs laid.

Laboratory experiments on egg laying were carried out in 1943 and 1944. The cage consisted of a hurricane lamp globe placed on the surface of clean sand contained in a 4½-inch diameter pot. A piece of muslin held in position by a rubber band closed the top of the globe. The pot stood in a saucer to which water could be added when necessary to keep the sand moist.

Fruiting spurs from the variety Lane's Prince Albert were stuck in the sand to provide food and the normal egg-laying habitat. Each pot was furnished with three pairs of weevils. Food was changed every other day until laying began, then daily. There were five replicates.

In 1943 the weevils were collected from the orchard on March 25th. One female died the following day and was replaced ; no other deaths occurred until the end of May, a month after laying ceased, so this method was regarded as eminently satisfactory, considering the difficulties experienced by previous workers in keeping weevils alive in confinement. Eggs were counted by dissecting the buds under a binocular microscope. Oviposition began during the period March 29th-31st and continued at a steady rate until April 17th. A few more eggs appeared up to April 21st when laying ceased. The total number of eggs in the several cages was 117, 125, 131, 133 and 148, representing an average of 43·6 per female.

Between June 1st and September 30th all but six weevils died, and by March, 1944, only one female and two males survived ; but even this demonstrated that the adult Apple Blossom Weevil could live for two years. This female laid 38 eggs during the first 16 days of April, 1944, dying a little later, as did the males. As she was caged with two other females in 1943 it is not definitely known whether any eggs were laid by her then, but the uniformity of the cage totals favours this assumption. There is thus strong evidence that some weevils live for two years and oviposit each season.

Egg laying trials were carried out under similar conditions in 1944. The weevils were taken from sack bands in January and kept in gauze tins without food until March 27th, in order to obtain some information on the feeding period necessary before oviposition could begin. Five males died during the oviposition period but only one female, and she lived until April 21st, a few days before laying ended. In three cages eggs were present by April 3rd, indicating that the pre-oviposition feeding or maturation period need be only six days. Oviposition continued, as in 1943, at a steady rate until April 17th, then decreased until it came to an end on April 27th. The total number of eggs in the several cages was 97, 110, 144, 145 and 187, making an average of 45·5 per female, a number which agreed excellently with the previous year's figure.

Nine of these weevils were alive on October 1st, and one female and four males survived the winter. Only seven eggs were laid by this female in 1945, but she is still alive at the time of writing, September 30th, 1945.

In 1944 an additional cage contained six females only, which were intended as reserves should any of the others die before egg laying began ; all remained alive throughout the spring months but no eggs were laid, doubtless because mating did not take place. Five were alive in October and two overwintered successfully. After mating in 1945 they laid a total of 62 eggs and both were alive on September 30th, 1945.

Another series of trials was run in 1945 to obtain more information on the minimum time that need elapse between feeding and egg laying. Weevils were collected from hibernation in February and kept without food until March 19th, by which time egg laying in the field had been in progress for at least four days. Five cages were set up as before and food provided. By March 23rd eggs were present in all the cages. This showed that only four days need elapse between feeding and laying.

From the results of these laboratory trials the following points emerge :—

(1) The female lays about 45 eggs at a steady rate in just over three weeks. This agrees well with an estimate made by Theobald (1897) who dissected up to 60 eggs from individual females. Speyer (1923) obtained 144 eggs from a female which oviposted in 1922 and 1923, and Wiesmann (1944) mentions an average figure of 30-40 as being the total egg production of females under favourable field conditions.

(2) Some weevils live for at least two years and lay eggs during the second year. There are strong reasons for assuming that these also lay during their first spring, as Speyer (1923) found, but definite evidence is lacking.

(3) No eggs are laid unless mating takes place.

(4) The interval between first feeding and laying need be no more than four days.

Field records give figures approximating very closely to those obtained in the laboratory. A longer oviposition period would be expected under natural conditions where the adult population consisted of individuals which had been on the trees for varying periods, but two

factors have to be considered, namely the length of time that the buds are attractive to the egg-laying female and the so called maturation period. From Fig. 3 it can be deduced that egg laying ceases at the pink bud stage, for the period between the discovery of the first egg and first larva is approximately ten days ; an equal period must therefore be deducted from the date when eggs are last observed in the buds, allowing for incubation, to arrive at the date when these were deposited. Each year this coincided with the pink bud stage. As has been demonstrated in laboratory experiments, the maturation period, at the time when laying begins, need be no more than four days. Thus, though the weevils which are first out of hibernation may feed for two or three weeks before oviposition it is evident that with later arrivals this interval is much reduced. This explains why egg laying proceeds so uniformly and rapidly in spite of the fact that most of the weevils arrive on the trees only a few days before eggs are first discovered in the buds. The limiting factor appears to be the condition of the buds, as until the bud-burst stage no oviposition takes place, but afterwards the number of eggs rises steadily. There is little, if any, correlation between emergence dates and egg laying, as would be expected from the laboratory results showing how short the pre-oviposition period need be.

The larva and pupa.

On hatching, the young larva feeds indiscriminately on the anthers, eventually devouring them all, together with their filaments and the styles. In the course of this feeding the petals get nibbled, at first where the tips are interlocked, then further down the sides and finally at the bases. This basal injury prevents the flowers from developing, and the unopened petals turn brown to form the characteristic capped blossom. By this time the larva is fully fed, has changed from white to yellow and lies well protected by the dead petals in a saucer-shaped hollow over the ovary. A few days after the final meal the larva changes into a pupa.

Every year the later laid eggs hatch quite normally, but the bud is so far advanced that it opens before the larva has damaged the base of the petals. These larvae perish, though the proportion in relation to the total is very small. Whether the season is early or late there are always approximately four weeks between the bud-burst and pink bud stages. If the weather is particularly fine and warm and reduces this interval it has a corresponding effect on the larva by hastening its development.

Reference to Fig. 3 will show that the columns, each of which represents the total of all stages found in a sample, remain relatively constant after egg laying has been in progress for three weeks. In theory, once oviposition has ceased they should be equal, but the heterogeneous collection of rootstocks gave trees of varying vigour and blossoming times, so that differences in the samples should be attributed to variable material rather than to inadequate sampling. If the proportions of the various stages are studied it will be found there is a steady trend throughout.

It has been noticed that after the dead petals have hardened a strong wind will cause some of them to break away from the calyx. This is probably due to jarring rather than to branches actually hitting the blossoms. Considerable reduction in sample populations was recorded in 1943 after a rough period in mid-May and is shown in Fig. 3 by a reduction in the larvae and pupae found in samples from these dates onwards. In addition, during the pupal period, small numbers of capped blossoms are occasionally noted having irregular holes bored through the dead petals, the pupa being missing. This type of injury is very suggestive of attack by insectivorous birds, probably tits.

The adult.

For a few days following the final moult the young adult remains within the capped blossom whilst the chitinous exoskeleton hardens. A hole is then gnawed through the dead petals or the base of the calyx and access gained to the leaves. The effect of this is shown in Fig. 3 where the totals represented by the columns decline, due to adults escaping from the capped blossoms. The small population of weevils which still survive after egg laying is rapidly augmented by the new brood, and by mid-June the population of adults is at its height (Fig. 2).

It will be noticed that the peak populations of weevils which emerged from hibernation were of a similar order each year. Uniformity also exists between the June peaks in 1943 and

1944, but in 1945 the total of freshly matured adults was treble that in the previous years. This cannot be due to a greater infestation of the sampled plot, for the number of weevils tapped and the eggs laid (Fig. 3) approached very closely the totals obtained in 1944. At present no explanation is available.

Considerable feeding takes place from the undersides of the leaves where small areas are skeletonized, with the upper surface left intact. During June, 1945, it was observed that freshly emerged adults occasionally fed on young apples. The damage was only superficial and very similar to the leaf feeding—small areas being excavated to a maximum depth of two millimetres.

Hibernation.

Three weeks after emergence the adults begin moving into sheltered positions in preparation for hibernation. This process involves a general dispersal, and during the latter half of June weevils can be found in many situations. Besides congregating under loose bark and among sacking ties on the apple trees and stakes they can be tapped from hedgerows and swept from

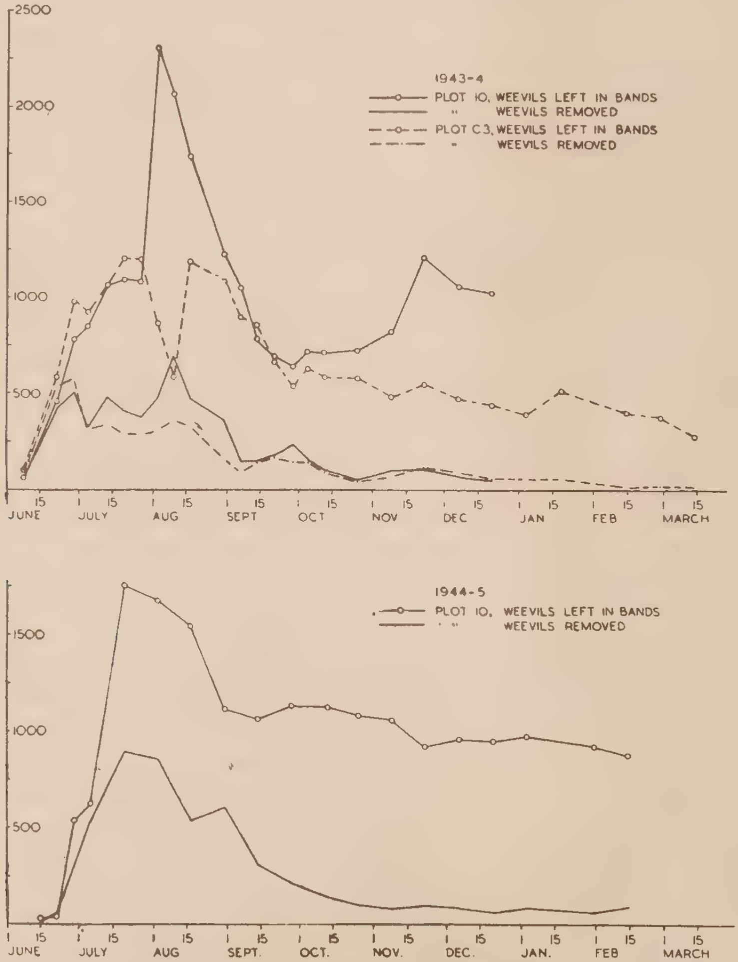

FIG. 4.

Variation in weevil populations in sacking bands.

grassy banks in the vicinity of the orchards. Where a piece of woodland is situated nearby, as so often occurs in Kent, the shelter afforded by the trees, stumps and detritus covering the soil attracts many weevils. Some seek temporary rest in the curled, dead leaves remaining on the trees, and in cordon orchards the bamboo canes used for training purposes make ideal winter homes. Others descend to the surface soil, more especially if turf or a thick growth of weeds is present. When searching in such diverse habitats it is extremely difficult to compare the results, but in the writer's opinion nearly all weevils hibernate above the level of the surface soil. Without doubt the greatest numbers can be found under loose bark and in cracks and crevices of the apple trees themselves, or in similar situations immediately adjoining the orchards. For example, mention has already been made of the numbers seen on fencing posts during the peak emergence period ; these spend the winter in the cracks and can be found throughout the resting period. By sifting the surface soil beneath trees in September about three weevils per square yard have been found where grass or weeds gave a good cover but none at depths greater than one inch or where the surface was bare.

The movement into hibernation has been studied by placing sacking bands around the trunks of apple trees and the results are in general agreement with those of Massee (1925). In 1943 the block comprised 56 trees, and the bands were inspected weekly ; in 1944, 50 trees were used and inspected once a fortnight. From alternate bands all weevils were removed and killed, so that the numbers entering at known intervals could be recorded. In the remainder the weevils were counted with as little disturbance as possible. Fig. 4 illustrates how the population in the bands increased rapidly from mid-June until late July or early August when a maximum was reached ; it then decreased until mid-September after which, with the exception of one plot in 1943, it remained relatively uniform. If the graphs showing the numbers arriving at weekly (1943-44) or fortnightly (1944-45) periods are now studied a period of considerable activity is noted until September, corresponding with the initial increase and decline in the other bands, followed by a small movement into these bands throughout the autumn and winter.

Apart from any disturbance caused by each inspection these two sets of results suggest that weevils first seek any shelter available, hence the high populations quickly attained. A period of six weeks or so follows, ending in the latter part of September, when more discrimination is used, many leaving their initial winter homes to find more suitable quarters. Reference to the populations on the trees (Fig. 2) does not indicate that any weevils return to feed, for the numbers obtained by tapping decrease as rapidly as the populations are built up in the bands and then remain consistently low. It is much more likely that this movement represents entirely a search by the weevils for the most comfortable hibernating positions.

Why is there a small but constant movement into the bands throughout the winter ? An experiment in 1944 gave indications of the probable answer. On September 5th bands were placed on twenty-seven trees ; above nine of these a ring of grease was applied to the trunk to prevent weevils descending ; similarly below the band on nine more trees, whilst the others were left ungreased as controls. These trees were chosen because they had practically smooth trunks which meant that few if any weevils would be hibernating on them. Thus, any entering the bands would come from either the branches or the soil. Table I gives the results, all weevils having been removed at each inspection. It will be seen that the totals

TABLE I.

Banding with sacking and grease to study movement of weevils.

Date.	Number of weevils in 9 sack bands.		
	No grease band.	Grease band above.	Grease band below.
19/9/44 ..	81	93	10
19/10/44 ..	170	204	34
20/11/44 ..	218	187	80
20/12/44 ..	53	54	18
20/2/45 ..	29	29	10

for the control bands and those grease-banded above are very similar, whilst where the grease-band was situated below the sack band only one quarter of the number was found. This indicates that most of the weevils entering the bands after the majority have gone into hibernation come from the soil, further proof being provided by the muddy appearance of many specimens. It is probable that those hiding in the surface soil find conditions unsuitable once the earth becomes sodden, and are induced to seek drier quarters.

Further reference to Fig. 2 will show how greatly the adult population differs before and after hibernation. In 1943-5 the weevils present on the trees in June were always three to four times more numerous than in the following April, which means a loss of approximately 70 per cent. during the hibernation and emergence periods. Part is accounted for by mortality during the winter months and the remainder by failure of the adults to return to the trees on which they were reared. Inspection of any appropriate habitat will reveal corpses and body fragments together with living weevils to illustrate losses during hibernation. Bondy and Rainwater (1942) found that winter mortality of the Cotton Bollworm (*Anthonomus grandis* Boh.) was high, sometimes approaching 99 per cent. and closely correlated with minimum temperatures during the quiescent stage. With *A. pomorum* the figure is lower, probably in the region of 50 per cent., but no relationship between survival rate and weather conditions is apparent. In theory, cross migration from one orchard to another should balance losses due to the second cause, but in practice this is not so, for many weevils do not return to apple trees in the spring. This has been noticed most clearly in the large woodlands near Maidstone where, many hundreds of yards from orchards, Apple Blossom Weevils can be tapped from rowan (*Sorbus aucuparia*) and hawthorn trees (*Crataegus oxyacantha*) throughout the egg laying period. These represent a portion of the overwintered population which fails to find its cultivated host plant, the apple, in the spring.

Wiesmann and Fenjves (1944) who made an extensive study of the hibernating weevil in Switzerland conclude that the majority spend the winter elsewhere than on apple trees, and none in the soil. Their view agrees with the above observations that the most suitable habitat is probably under bark either of fruit trees or nearby forest trees.

Host plants.

In Great Britain, the apple, both wild and cultivated, is the only important host. Originally, no doubt, the weevil struggled to maintain its numbers on scattered wild crabs growing amongst other forest trees. With the advent of domestic varieties the host became more common and, as so often happens, the weevil found the new conditions conducive to more rapid multiplication ; this, in conjunction with a lessening of the dangers to which it was formerly exposed, meant that only a matter of time was necessary for it to become a pest.

All apple varieties commonly grown at the present time may be attacked to a certain extent, but most damage occurs on Lane's Prince Albert, Cox's Orange Pippin, Bramley's Seedling and James Grieve. The relative loss appears to depend on the varieties in an orchard ; for instance, at East Malling one plot consists of Lane's, Laxton's Superb and Allington Pippin, of which the first named is always most heavily attacked, whereas on certain farms where Lane's is not grown Laxton's Superb is considered a susceptible variety. Worcester Pearmain is one of the varieties least attractive to the weevil.

Early in the season before apple buds are bursting, pear is used as an alternative source of food by weevils just out of hibernation. A few early eggs are laid in the buds and all the immature stages passed within. Similarly, slight feeding takes place on leaves in June, but pear has little attraction for the weevils whilst they can obtain food from apple. Quince and medlar are also occasionally attacked, and Miles (1923) mentions plum foliage being accepted by adults as food in June.

Parasites and Predators.

Imms (1918) and Thompson (1943) list respectively, fourteen and thirty-three species of insects as parasites of *A. pomorum*. Only one, *Pimpla pomorum* Ratz., could be bred by Imms from material collected in England, and similar results have been obtained by other workers in more recent years. *P. pomorum* lives as an ectoparasite on the larva or pupa within the

capped blossom. Adult parasites begin emerging about the same time as the weevils but continue to come out over a longer period. Apart from occasional records of imagines in the winter months nothing more is known about the habits of this little ichneumon, though it is surmised that another generation is passed during the summer, possibly utilizing a lepidopterous larva as host.

In 1916 Imms bred 349 individuals of *P. pomorum* from 1,270 capped blossoms, obtained from an orchard in the Chatteris district of Cambridgeshire. This high percentage gave hopes of biological control. Some years later Massee (1925) recorded only 0·1 per cent. attacked by this parasite at East Malling, and results during the past three years in Kent and Essex have been of a similar order. Collections of capped blossoms varying from 3,000 to 7,000 per year have yielded 0·2 to 0·6 per cent. of these parasites. So few are unlikely to materially reduce any infestation.

As mentioned earlier, the pupae may be extracted from capped blossoms, probably by tits, and a Canterbury fruitgrower reports that the Wood Ant, *Formica rufa* L., will carry off to its nest the immature stages of this weevil.

Adults are sometimes attacked by a fungus, *Beauveria globulifera*, during the hibernation period, but it does not cause any appreciable reduction in the population.

SUMMARY.

The life history of the Apple Blossom Weevil, *Anthonomus pomorum* L., is described with special reference to the periods when adults emerge from hibernation and eggs are laid. Under Kent and Essex conditions weevils leave hibernating quarters over a period of approximately five weeks, beginning in late February or early March. A close correlation exists between temperature and numbers returning to the apple trees, very little activity being noted unless the maximum daily temperature exceeds 50° F. Egg laying begins when the fruit bud reaches the bud-burst stage and continues for three weeks. Under controlled laboratory conditions fifteen females laid an average of 43·6 eggs in 1943; the same number averaged 45·5 eggs in 1944. A few males and females live for two years; oviposition also takes place during the second spring. Only four days need elapse after females have taken their first meal until egg laying begins.

The weevils go into hibernation about three weeks after emergence from the capped blossoms; at first any available shelter is utilized, followed by further movement in search of more comfortable quarters, which continues on a reduced scale throughout the winter.

Pimpla pomorum Ratz., is the only parasite that has been bred during the period 1943-45, the rate of parasitism being low, between 0·2 and 0·6 per cent.

ACKNOWLEDGMENTS.

The author wishes to express his thanks to Dr. A. M. Massee whose interest and many helpful suggestions have greatly aided these studies; to Mr. S. C. Pearce who devised the sampling method; and to the joint organization composed of the Agricultural Research Council, the Pettar Society of Winter Wash Manufacturers and the Associated Fruit Growers of Essex, Ltd., which provided facilities for the studies in Essex.

All the Essex records were taken by the staff of the Field Laboratory, Great Braxted, under Dr. F. C. H. Gayner in 1944 and Mr. M. D. Austin in 1945. For a considerable period during the spring months these workers devoted much of their time to the Apple Blossom Weevil problem, and the author's sincerest thanks are due to them for their constant co-operation.

Finally, thanks are due to those members of the Associated Fruit Growers of Essex, Ltd., who so kindly rendered their orchards available for life-history records.

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STUDIES IN IRON DEFICIENCY OF CROPS

I. PROBLEMS OF IRON DEFICIENCY AND THE INTERRELATIONSHIPS OF MINERAL ELEMENTS IN IRON NUTRITION

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Iron deficiency is one of the most serious nutritional problems in fruit culture and occurs in every major fruit growing area of the world. It has been reported as affecting most kinds of fruits and often leads to the total failure of fruit growing enterprises over large areas. The deficiency may also seriously affect the growth of timber trees, especially conifers.

Vegetable crops are not so prone to the deficiency though particular crops such as spinach and Brassicae may be affected on some soils.

In agricultural crops it is rarely a serious problem, but there are special circumstances under which even cereal crops, sugar beet and potatoes may suffer from the deficiency (34).

In the field the most serious instances of the deficiency occur on calcareous soils, where the trouble has been termed lime-induced chlorosis (1, 30, 31, 33, 37.) It is this trouble which is associated with widespread failures of crops and which has been the subject of the majority of investigations on iron deficiency in the past.

One other type of iron deficiency in the field which has been of special scientific interest as well as of economic importance is that of iron deficiency of pineapples in Hawaii, where the deficiency occurs on highly manganiferous soils and appears to be induced by the excessive manganese content of these soils (14, 18.)

The special importance of iron deficiency in the field lies in the difficulty of its control. It is, in fact, the most difficult of all known mineral deficiencies to remedy, and the measures hitherto suggested are either unsatisfactory, cumbersome or inconvenient. The practical difficulties in control lie in the facts that soil treatments, such as treatment with iron salts or sulphur or "grassing down", are generally unsatisfactory or of limited application and resort must be made to spraying or injection methods. The latter of these two alternatives can be applied only to trees, and although effective for some crops, e.g. apples, may give rise to gumming in stone fruits ; and in spite of recent improvements in technique it is still tedious to carry out. Sprays are unsatisfactory for two reasons : firstly they are often damaging at effective rates and may thus lead to loss of crop, and secondly the effects are transient and often several applications must be made during a single season to keep the plants sufficiently supplied with iron. This last point arises because, in instances of iron deficiency, the iron in the plant tissues is relatively immobile.

In studying problems of iron deficiency, investigations have been carried out with plants both in the field and in sand and solution cultures, and in considering the results obtained under these two sets of conditions, it seems necessary to distinguish clearly how far the results from pot culture experiments are applicable to problems in the field. The importance of this distinction will be made clear in the discussion on iron/manganese relationships.

In connection with problems of iron deficiency in crops one further point calls for special comment. Iron deficiency was the first nutritional cause of chlorosis to be recognized and there is still a tendency to associate the two conditions in particular instances without adequate proof. Chlorosis may arise from causes other than iron deficiency, as for example in albinism, where iron may not be concerned (9, 16), in manganese deficiency (36), in excess of this element in acid soils (35), and in magnesium deficiency (34). On the other hand, as will be clear from the sections below, iron deficiency may arise as the result of toxic concentrations or deficiencies of other elements, which may either decrease absorption of iron from the soil or render it less mobile within the plant.

Iron deficiency problems, in relation to causes, may be considered under the following headings : (*a*) simple deficiency of iron (probably occurring only under pot culture conditions) ;

(*b*) lime-induced chlorosis, occurring on calcareous soils ; (*c*) deficiency resulting from deficiencies of other mineral elements (e.g. potassium) ; (*d*) deficiency resulting from excesses or toxicities of mineral elements (e.g. phosphorus, manganese, zinc, copper).

In addition to these points there are conditions which affect iron nutrition which have been shown to be contributory factors under both field and pot culture conditions, viz. soil moisture and temperature (19) and light.*

In the experiments to be described in the present series of papers special attention will be given to the interrelationships of mineral elements in iron nutrition, and the discussion which follows outlines relevant points in connection with the problems which have emerged from previous work.

In discussing previous results a point of difficulty arises in connection with the iron content of " iron deficient " plants. The data show discrepancies in respect of the " total " iron content of green and chlorotic plants, and it is generally recognized that a division of the iron into " active " (functional or soluble) and " inactive " (residual or insoluble) iron is necessary.

This division, however, is as yet arbitrary, and different investigators have used different methods of fractionation, thus rendering strict comparisons difficult. In spite of this difficulty, however, the main points of the various types of iron deficiency are fairly clear.

Simple deficiency of iron.

Lindner and Harley (16) compared the effects of simple iron deficiency produced in solution cultures with those which result in instances of lime-induced chlorosis. They found that both showed low amounts of " soluble " iron in the leaves but differed in the Ca/K ratio, from which it may be concluded that lime-induced chlorosis is not the result of a simple deficiency of iron.

Manganese/Iron antagonism.

Shive and his co-workers (27, 28) have shown a clear antagonism between manganese and iron. In water cultures, using soya beans, iron deficiency was produced by high manganese/iron ratios in the nutrient solution and *vice versa* ; moreover it was shown that optimal growth resulted when the ratio Fe/Mn approximated to 2·0 in the nutrient solution and in the sap of the tops and roots of the plants. It was also shown that these optimal conditions coincided with the highest respiratory rates of the plants. These results have received ample confirmation *in solution cultures*, notably by Bennett (2), Chapman *et al.* (6), Pearse (24) and Chapelle (25) for a number of plants.

It is thus pertinent to enquire whether this antagonism is of crucial importance under any of the conditions of iron deficiency in practice, and in this connection it is necessary to examine the status of the two elements in particular under conditions of soil alkalinity and soil acidity.

Before doing so the special case of manganiferous soils (14, 18) requires mention. Here there seems general agreement that the high manganese content of the soil is the decisive factor in the iron deficiency chlorosis, though there is some difference of opinion as to the mechanism involved. Thus McGeorge (18) has concluded that the chlorosis is not a direct effect of manganese/iron antagonism but is caused by high calcium assimilation which results from the high manganese content of the soils. In this connection it may be observed that Chapman (8) found that a high calcium content of a nutrient solution aggravated manganese toxicity and increased the severity of iron deficiency. On the other hand, at Long Ashton, using sand cultures with adequate iron, manganese intake and toxicity effects were reduced in cauliflower and beans by increasing the calcium content of the nutrient solution (35).

Under conditions of soil alkalinity (high pH) instances of deficiencies of both elements are common, and in fruit plantations the deficiencies may occur side by side, depending sometimes on the particular kinds of fruit grown. Thus pears, which are highly susceptible to deficiency of iron and less so to that of manganese, may show iron deficiency whilst neighbouring apple trees may show signs of manganese deficiency. In some instances both deficiencies occur on a single tree and indeed it is not uncommon for the terminal leaves of shoots of fruit

* Unpublished data of F. G. Gregory and W. E. Brenchley on flax.

plants (e.g. apples, plums, peaches, raspberries), to show symptoms of iron deficiency and the older leaves of manganese deficiency.

Data are available for the manganese and iron contents of comparable green and chlorotic leaves of trees in typical instances of lime-induced chlorosis. In one case the comparison is between chlorotic leaves and others, previously chlorotic, which had been "greened" by an iron spray (16), whilst in others the green and chlorotic leaves are from trees growing in close proximity (8, 11, 30).

In the following data from Lindner and Harley (16), the whole of the Mn was soluble in 0·1 N.HCl.

LINDNER AND HARLEY.

	Fe.	Mn.
Greened	94	88
Chlorotic	35	31

It will be noted that the iron spray, in addition to increasing the Fe content, also greatly increased the content of Mn. It seems unlikely that manganese can have been an important factor in inducing the chlorosis in this particular instance.

The following data from Chapman (8), Thorne and Wallace (30), and Guest (11), again show that manganese was much higher in green than in chlorotic leaves (although the chlorotic leaves did not respond to manganese treatment) and it seems unlikely in these instances that the ratio Fe/Mn was causal.

CHAPMAN.

	Green.	Chlorotic.	Green.	Chlorotic.	Green.	Chlorotic.	Green.	Chlorotic.
MnO ..	0·028	0·013	0·042	0·031	0·043	0·031	0·049	0·022
Fe_2O_3 ..	0·10	0·06	0·16	0·11	0·28	0·11	0·33	0·28

THORNE AND WALLACE.

Means of all plants :	Fe.	Mn.
Green	132	21·2
Chlorotic	115	9·3

GUEST.

	Green.	Slightly chlorotic.	Severely chlorotic.
Fe. γ	3·9	3·2	2·8
Mn. γ	26·0	15·0	5·1

With increasing soil acidity both manganese and iron become increasingly soluble and it is held by some workers (15) that both may become toxic. Nevertheless it is necessary to enquire whether, in fact, with increasing acidity the solubility of manganese may not increase more rapidly than that of iron, and whether conditions of manganese toxicity, resulting in iron deficiency, may not occur.

The data of many workers show that the range of manganese found in plants is much greater than of iron, and that under strongly acid conditions the content of manganese may reach amounts well over 1,000 p.p.m.

An example of the ranges of Fe and Mn found in flax in the laboratory at Long Ashton (21) in a series of experiments on soils ranging from highly calcareous to strongly acid may be cited, which incidently shows how an application of common salt (NaCl) to an acid soil may greatly increase the manganese content of the plants, due to ion exchange, without materially affecting the iron status.

NICHOLAS (21).

	Centre C. Calcareous soil.	Centre F. Acid soil.	
		No salt.	Salt.
Fe (p.p.m.)	44	47	45
Mn (p.p.m.)	7·5	82	139

Similar results are shown for ranges of soil acidity in heather and pasture plants by Thomas *et al.* (29), whilst the "salt" effect was also obtained by Němec (20), on conifers by the use of potash salts and kainit.

Several instances of manganese toxicity in crops growing on acid soils have been reported, and in some of these chlorosis has been a symptom of the toxicity, e.g. tobacco (3) and beans (23, 35). In some plants, however, manganese toxicity does not produce chlorosis, e.g. barley, cauliflower (3, 35). Moreover, other symptoms may accompany chlorosis associated with excess manganese, e.g. tobacco (3, 10), and the visual pattern of the chlorosis may differ from that of iron deficiency, e.g. beans (35).

At Long Ashton attempts to cure the chlorosis in beans resulting from manganese toxicity, using a method which is effective where iron is deficient (painting the leaves with iron solutions), were entirely ineffective in decreasing the chlorotic condition.

Recently, however, a chlorosis of pineapples on acid soils in Puerto Rico (40) has been reported on, in which the chlorosis has been shown to be due to iron deficiency and which is controlled commercially either by ferrous sulphate sprays or by liming and is accentuated by increasing the acidity of the soil by dressings of sulphate of ammonia. The soils are high in water-soluble manganese and practically devoid of water-soluble iron.

When the chlorosis is cured by iron sprays the fruits still show an abnormal growth condition known as "short top".

It is concluded that the wide Mn/Fe ratio is responsible for the iron deficiency chlorosis and that the "short top" condition results as a direct effect of manganese toxicity.

It would thus seem that for cases of induced chlorosis on calcareous soils the operation of the Mn/Fe ratio is not a material factor and that, on acid soils, whilst the ratio may sometimes be important, manganese toxicity produces deleterious effects which are quite distinct from iron deficiency and which should not be confused with it.

LIME-INDUCED CHLOROSIS.

Investigations on this problem have been concerned with the availability of iron in calcareous soils and the mobility of iron within the plants, and there is evidence to show that both factors enter into the problem.

As regards availability, it has been shown that calcium or magnesium carbonates and factors which raise the pH of the soil render iron less available to plants (4, 12, 17). In pot culture studies it has been shown by Chapman (4) and by Guest (12) that finely divided magnetite may provide an available source of iron to plants in the presence of calcium carbonate, and by Guest (12) that powdered dolomite may induce iron deficiency even when magnetite is present.

The importance of ferrous iron has also been stressed (30) and the increase of chlorosis due to over-irrigation, prolonged wet soil conditions and low soil temperatures has been noted in a number of crops, e.g. Citrus (6) and flax (19).

Bennett (2) has pointed out that chlorosis is most likely to occur when iron is deficient early in the season, since it is more effective at that time, whilst Millikin makes the point that flax crops which survive the deficiency early in the season may later show complete recovery (19).

The action of a grass cover crop in correcting lime-induced chlorosis in trees has been explained by Chapman (8), from data in lysimeter studies, by the lowering of the pH value (generally of the order of from 0·1 to 0·2 points). In Chapman's studies a rise in pH values occurred in passing from summer to winter of approximately 0·4 points (from 7·6 to 8·0 pH).

Whilst in earlier investigations data obtained for total iron in green and chlorotic leaves

showed a lack of uniformity, in later work there is good agreement on the point that chlorotic leaves show lower amounts of "soluble" iron than green leaves, and Bennett (2) has shown that a close relationship exists between "active" iron and chlorophyll content.

There is one novel feature, as yet unexplained, in chlorotic leaves in cases of lime-induced chlorosis which has been the subject of recent investigations and theorizing as regards the nature of this particular type of chlorosis (2, 16). It is the fact that chlorotic leaves, when compared with similar green leaves, show much higher amounts of potassium and somewhat lower amounts of calcium, so that the ratio Ca/K is much lower in the chlorotic leaves (30, 31, 37).

Lindner and Harley (16) have suggested as a working hypothesis that the high potassium content of chlorotic leaves causes the iron to be displaced by potassium in the chlorophyll enzyme, thus leading to its inactivation. Bennett (2), however, does not consider this disturbed Ca/K balance as causal.

On balance, the evidence obtained suggests that in lime-induced chlorosis factors affecting iron movement, both external and internal to the plant, are concerned.

POTASSIUM DEFICIENCY.

In some plants, notably some plums and peaches, and barley and flax, deficiency of potassium results in chlorosis in addition to the more usual leaf scorch, whilst in many plants a fading of the chlorophyll may be noted after prolonged potassium deficiency. In such instances it is usual to find that the leaves show high levels of Ca, Mg and P and a low level of K (32).

In the above simple cases of potassium deficiency, chlorosis and scorch symptoms occur together on the same leaves. There are, however, numerous cases of fruit trees, on calcareous soils, where the distal, younger leaves show typical signs of iron-deficiency chlorosis and the older leaves scorching symptoms, with or without the potassium deficiency type of chlorosis. In these latter cases two separate sets of conditions may be concerned.

In the *simple* cases in fruit trees we have never been able, at Long Ashton, to decrease the chlorosis by the usual iron sprays effective against lime-induced chlorosis, though Bennett (2) reports that improvement can be effected by using "heavy doses" of iron.

Similarly, with barley in the field, we have failed to effect improvement in potassium deficiency chlorosis by a ferrous sulphate spray (1 oz. per 2 gal. water + spreader) though in sand cultures with oats, chlorosis in potassium deficient plants has been entirely cured by sprays of ferrous sulphate and ferric citrate (both 0·1 per cent.) and growth greatly increased. In a subsequent paper of this series evidence will be discussed relative to the mutual effects of iron and potassium in potatoes.

Chapman (5), using Citrus in solution cultures at pH4, also found that iron deficiency occurred in trees not receiving potassium.

Hoffer (13) has also shown that, in maize, when potassium is deficient, iron is precipitated in quantity at the nodes.

The above evidence suggests some association between potassium status and iron mobility within the plant.

IRON/PHOSPHORUS RELATIONSHIPS.

Many investigators have confirmed the observations of Olsen (22) that phosphorus in neutral or alkaline cultures may result in iron deficiency; indeed it is common experience that the prevention of iron deficiency is a difficult problem in many solution cultures, due to soluble phosphates especially at high pH values. Thus, Sideris and Krauss (26) and Chapman *et al.* (7), using maize and Citrus respectively, showed that iron deficiency was induced in high phosphate cultures under slightly alkaline conditions. The former workers also showed that the addition of phosphates to alkaline soils depressed the growth of pineapples due to adverse effects on iron, whilst in acid soils phosphates were beneficial. Walsh and Clarke (38) also showed that the precipitating effect of phosphates in an acid peat soil was insufficient to bring about a deficiency of iron.

It may thus be concluded that phosphates are more likely to induce iron deficiency in soils under neutral or alkaline conditions than in acid soils.

Iron/Zinc relationships.

There are now on record a number of instances showing that excess of zinc may induce a deficiency of iron. Thus, Chapman *et al.* (7), state that in sand cultures iron deficiency chlorosis has been repeatedly observed in Citrus as the result of toxic doses of zinc, introduced either intentionally or accidently from the use of galvanized equipment. In one such instance, in a sand culture using a solution of pH 5·0, it was found that the roots of affected plants were high in iron whilst the tops contained only small amounts, indicating the immobilizing of the iron by the zinc within the plant. Zinc toxicity has also resulted in plants in sand cultures at Long Ashton from the use of water from galvanized tanks, and it is now routine practice to paint all galvanized vessels with bitumen preparations.

Schappelle (25) also reports the inducing of iron deficiency in pineapples in water cultures whilst Walsh and Clarke (38) have described an instance of iron deficiency in tomatoes in acid peat in which zinc was involved, apparently introduced from a galvanized water tank. In this case zinc intake increased with acidity, and the plants showed low iron contents of the young leaves but not of the older ones.

Examples of zinc toxicity are common in soils near zinc mines and spelter works and in most instances it has been reported that the toxic effects have been overcome or decreased by liming. Unfortunately in these cases the iron status has not been examined, although in instances examined by one of us (T.W.) chlorosis of the typical iron deficiency type has been in evidence.*

Interesting examples of zinc toxicity associated with iron deficiency chlorosis on soils of alkaline reaction derived from dolomitic limestone occur in the Mendip area of Somerset. The trouble is often so serious that arable cropping is precluded and even cereals may fail entirely. In these instances the plants are severely chlorotic and the chlorosis can be remedied temporarily by ferrous sulphate sprays. Chemical examination of the foliage shows extremely high values for both zinc and iron, from which it may be concluded that the iron is very effectively immobilized by the zinc. A comparison of healthy and severely chlorotic wheat and oats from the area is given in the following Table, from data supplied by D. J. D. Nicholas.

Crop.	Healthy.		Chlorotic.	
	Iron p.p.m.	Zinc p.p.m.	Iron p.p.m.	Zinc p.p.m.
Wheat	140	20	500	370
Oats	150	10	930	560

Iron/Copper relationships.

Willis and Piland (39), in an investigation of the beneficial action of copper in acid peats, found that the addition of copper to a nutrient solution resulted in iron deficiency chlorosis in corn and cotton. Copper had also a beneficial effect on manganese toxicity in acid peat, and it was concluded that copper entered into the soil oxidation-reduction system, producing beneficial effects when manganese was available in excessive amounts. From culture solution experiments it was concluded that copper was antagonistic to iron and that the antagonism occurred largely in the solution.

Copper toxicity in crops occurs in England in small areas on the Keuper Sandstone, due to the presence of mineral deposits in the soil layers, and also in the neighbourhood of copper mines. In instances observed by one of us (T.W.), affected crops have shown varying degrees of chlorosis suggesting iron deficiency but the deficiency has not actually been proved. It seems clear, however, from Willis and Piland's work that copper toxicity may be expected to induce iron deficiency.

* An instance has been observed of an induced iron deficiency in oats, kale, mangolds and sugar beet resulting from the application of a raw industrial sewage sludge containing zinc, to an acid sandy soil. Liming failed to remedy the chlorosis and an oat crop on the limed soil showed both iron and manganese deficiencies, the latter apparently induced by the lime dressing.

RELATIONSHIPS OF IRON TO OTHER MINERAL ELEMENTS.

Somers and Shive (28) have reported that in one experiment the addition of cobalt to a nutrient solution resulted in iron deficiency.

Chapman (5) reports the occurrence of iron deficiency in Citrus cultures from the use of a nutrient solution with relatively low Ca and high K contents and also following a prolonged deficiency of magnesium. Flax grown in calcium deficient sand cultures at Long Ashton has shown marked chlorosis which was cured in three days by an iron spray. In the field, examples of iron and magnesium deficiencies on the same plant are fairly common on such crops as apples and glasshouse tomatoes, but in these instances conditions are such as to suggest that the deficiencies have occurred independently, and no evidence of any interrelationship between them has been observed.

Finally, Bennett (2) and other workers have shown that chlorotic plants contain high proportions of soluble nitrogen compounds, from which it may be expected that the level of nitrogen nutrition may affect the severity of iron deficiency.

CONCLUSION.

From the foregoing discussion it will be clear that the problems concerned in iron deficiency are very complex and that many relationships of iron with other mineral elements may be involved both in the soil, external to the plant, and within the plant tissues. It is hoped that the present series of investigations will throw some light on some of these relationships and on others not yet examined.

SUMMARY.

1. Problems relating to the deficiency of iron in plants are discussed with special reference to the occurrence of the deficiency in the field and in pot cultures and to the interrelationships of iron to various mineral elements. It is shown that the problems are very complex and include questions relating to factors influencing the absorption of iron by the plant and the movement of iron within the plant.

2. It is pointed out that factors of importance in causing iron deficiency in solution and sand cultures are not necessarily of an equal degree of importance under field conditions, and results obtained in pot cultures should be tested on crops in the field to assess their applicability to practical field problems.

3. Iron deficiency problems may be grouped under four headings on the basis of causal factors, viz.:

(*a*) Simple deficiency of iron where the total supply of iron is inadequate (probably occurring only under pot culture conditions).
(*b*) Lime-induced chlorosis occurring on calcareous soils.
(*c*) Deficiency resulting from deficiencies of other mineral elements.
(*d*) Deficiency resulting from excesses or toxicities of other mineral elements.

4. Although manganese has been clearly shown in solution cultures to be antagonistic to iron it appears unlikely to be an important factor in lime-induced chlorosis. On acid soils manganese may be toxic to many plants, but many of the toxic effects appear to be distinct from iron deficiency, and the importance of the ratio Mn/Fe in producing iron deficiency in acid soils requires further study.

5. The outstanding characteristic in the leaves of plants suffering from lime-induced chlorosis is the high content of potassium and the low Ca/K ratio. Available evidence suggests that this condition is an effect of the chlorosis and not a cause.

6. Iron deficiency may be induced by potassium deficiency, but in examining this question there is need for distinguishing between *simple* instances of potassium deficiency, in which iron deficiency may be induced, and instances in which deficiencies of the two elements occur simultaneously as separate problems.

7. Phosphorus is a common cause of iron deficiency in solution cultures and may bring about iron deficiency under neutral and slightly alkaline conditions in soils, but it seems less likely to be a factor of importance in acid soils.

8. Iron and zinc show antagonism and zinc may cause iron deficiency in both solution cultures and in soils, particularly in acid soils.

9. Iron and copper also show antagonism and copper may affect the availability of both iron and manganese to plants.

10. Cobalt may also cause iron deficiency, and iron nutrition appears to be affected by the status of magnesium and by the Ca/K ratio in the nutrient medium. Iron deficiency results in high proportions of soluble nitrogen in the leaves of plants.

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CONTROL OF THE APPLE BLOSSOM WEEVIL, *ANTHONOMUS POMORUM* L.

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INTRODUCTION.

Early in 1943 the senior author (G. H. L. D.) took over the Apple Blossom Weevil investigations started two years previously by Greenslade (1945) who, in addition to obtaining more biological data was also testing a series of chemicals with deterrent properties. About the same time two new insecticides, dichlorodiphenyltrichloroethane (D.D.T.) and benzene hexachloride (666) (of which the most active isomer is commonly termed "Gammexane"), were just becoming available for preliminary tests from which it soon became evident that successful control measures were more likely to be obtained by attempting to kill the weevil rather than to repel it.

Biological studies (Dicker, 1946) indicated that adults continued to emerge from hibernation for at least a week after oviposition began; and as no injury of importance to the host was caused until eggs were actually laid in the buds, emphasis was placed on methods of control by which an insecticide could be applied as rapidly as possible when egg laying was judged imminent. This inevitably led to the choice of a dust rather than a spray, in spite of the disadvantages caused by adverse weather conditions reported by Steer and Thomas (1935). Furthermore, the majority of fruitgrowers already had a full spray schedule, and control measures against the Apple Blossom Weevil involved an additional spray, because the beginning of egg laying, which corresponds closely to the bud burst stage of the apple, falls between the time of the petroleum spray and that of the green bud lime-sulphur application. Experience in field trials during the past three years has shown that a sufficient number of calm periods can be expected at about this time to apply a dust, with a few days delay at the most.

Whilst much of the work described in this paper was carried out at East Malling, during 1944 and 1945 field trials also took place in Essex. This was made possible by the authors' participation in investigations concerning this pest, initiated in December, 1943, through the collaboration of the Agricultural Research Council, the Pettar Society of Winter Wash Manufacturers and the Associated Fruit Growers of Essex, Ltd. The facilities provided by this arrangement materially assisted in the development of a method of adequate control of the Apple Blossom Weevil by enabling experiments to be conducted under the conditions prevailing in a second important fruitgrowing area.

HISTORICAL.

Towards the end of the nineteenth century the damage done by Apple Blossom Weevil was the subject of so many enquiries that Theobald (1897) published a special leaflet setting forth the habits of this pest. It is interesting to note that the preventive measures suggested at that time consisted of (1) jarring the weevils from the branches and catching them on tarred boards, (2) the collection and destruction of capped blossoms and (3) grease-banding to prevent the females gaining access to the branches. Spring spraying with a kerosene emulsion, to act as a deterrent, and arsenate of lead, as a poison, were also considered worthy of trial. Later, lime washing the trees was added to this list and poultry running in orchards were claimed to devour many weevils.

By 1920, *A. pomorum* was causing sufficient injury to apple trees in pruning trials at East Malling to obscure the results. This led to a thorough investigation into the prevailing methods of control, started by Hatton (1921) and continued by Massee (1925). The results indicated that none of the above mentioned methods was satisfactory, but banding the trees to trap the hibernating adults and then removing the bands in autumn and killing the weevils gave promise of success. Banding appears to have been first practised on the continent, for Lees (1921) mentions work in the Tyrol, about 1897, and Theobald (1909) quotes an advertisement

* In charge of the Field Laboratory, Great Braxted, Essex, in 1944 and 1945 respectively.

from a firm in Nackenheim-on-Rhine offering corrugated cardboard bands for trapping larvae of the Codling and Plum Fruit Moths and the Apple Blossom Weevil. Massee used folded sacking, and this has remained a standard recommendation to the present day. Variations of the banding method have been employed, such as the impregnation of the bands with chemicals both to attract and to kill the weevils (Massee, Greenslade and Brair, 1937 ; Massee, Greenslade and Duarte, 1938), but the results obtained have been inconsistent.

Hey, Massee and Steer (1934) and Steer and Thomas (1935) experimented with Derris dusts (containing 0·15 and 0·36 per cent. rotenone) against the adult weevil during the egg-laying period. Each strength reduced the capped blossoms by approximately 50 per cent. but the unfavourable weather conditions often prevailing at this time of year were considered a serious obstacle to the use of dusts. Steer and Thomas failed to obtain any control with a barium silicofluoride dust. In 1941 Greenslade (1945) again used a Derris dust (0·25 per cent. rotenone) with but little success. He decided that a new approach was necessary and tested a series of chemicals in the hope that one or more might possess sufficient deterrent properties to keep the weevils off the trees during the normal oviposition period.

Continental workers have tried many of the above mentioned methods and, in addition, have obtained most conflicting results with carbolineum washes. More recently Hamf (1938) and Speyer (1939) claimed good results from a Pyrethrum spray ; and Thiem (1938) with 5 and 10 per cent. dinitro-*o*-cresol dusts, while Wiesmann (1943), using a 1 per cent. Gesarol (0·05 per cent. D.D.T.) spray, reported excellent control in preliminary trials.

LABORATORY DUSTING TRIALS.

Materials and methods.

Adults were collected from the plantation on the day each test was started by tapping them from the branches on to a beating tray and then brushing them into glass tubes. Each tube contained the number of weevils needed for a single cage, thus no further handling was necessary until the tests were undertaken. Just before the trials began all weevils were tapped to the corked end of each tube which was then laid horizontally on a bench with its glass end facing a window. By utilizing the weevils' positive phototropic response it was possible to recognize any injured individuals (which were replaced by healthy ones before treatment began), for all the active weevils quickly ran to the illuminated end of the tube.

Each cage consisted of a flower pot filled with moist, clean sand on which was placed a hurricane lamp glass having its upper end closed with a piece of muslin held in position by a rubber band. Each pot stood in a saucer to which water could be added when necessary to keep the sand moist. Food, in the form of fruiting spurs of apple, was stuck in the sand ; fresh, clean spurs were added when necessary, usually after four or five days. As far as the Apple Blossom Weevil is concerned this type of cage appears perfectly satisfactory ; every year there were periods when mortality was relatively high among the controls and the cause was eventually traced to the contamination of the weevils, during the routine orchard spraying, with petroleum or D.N.O.C.-petroleum. In later tests those affected by these sprays had already perished in the orchard before the collections were made. Using similar cages for egg-laying experiments Dicker (1946) kept weevils alive for seven weeks without loss.

Weevils can be obtained in sufficient numbers only between late March and mid-April. The shortness of this period seriously limits the laboratory tests which can be undertaken each year and on no occasion was it possible to plan a field trial based on the current year's results. Adults of the succeeding generation are on the trees during June but appear to be more resistant than overwintered weevils. The difference in the results obtained when conducting tests in March and June will be discussed later.

Each insecticide was given a preliminary test by placing both weevils and food in a cage and puffing dust through the muslin. By this method weevils, food, and all the internal surfaces became coated with a fine layer of dust. If negative results were obtained under such conditions no further tests were undertaken with this particular material. Materials showing promise in preliminary tests were given further trials in which :

(*a*) Weevils were dusted and placed in cages with clean food.

(*b*) Food was dusted and placed in clean cages to which undusted weevils were added.

TABLE I.

Preliminary dusting trials against Apple Blossom Weevil.

Date started.	Treatment.	Total No. of weevils.	% Kill.
22/3/43 ..	1% Lethane HE-60	50	0
	1% Lethane 384	50	0
	1% Dinitro-*o*-*cyclo*hexylphenol	50	2
	10% Derris	50	2
	10% Dinitro-*o*-cresol	50	100
	Control	50	0
26/3/43 ..	1% Dinitro-*o*-cresol	100	16
	5% Dinitro-*o*-cresol	100	89
	10% Dinitro-*o*-cresol	100	99
	Control	100	5
30/3/44 ..	5% Dichlorodiphenyltrichloroethane (D.D.T.) ..	100	100
	Derris-Lethane	100	9
	1% Rotenone (Derris)	100	14
	1% Rotenone (Lonchocarpus)	100	6
	Control	100	4
2/4/44 ..	1% Benzene hexachloride (666)	100	100
	3% Benzene hexachloride (666)	100	100
	Control	100	7
16/4/44 ..	5% Dinitro-*o*-*cyclo*hexylphenol	100	13
	Control	100	1
19/4/44 ..	5·7% Rotenone (Lonchocarpus)	100	83
	Control	100	2

Records were taken each morning of the numbers dead and paralysed. For the latter category an arbitrary standard had to be adopted and finally it was decided to include all weevils *on the sand and incapable of normal movement*, varying from those exhibiting a slight stagger when walking to others lying on their backs and only just twitching their tarsi. Some were certainly omitted from the records during the first few days for it was observed that slightly paralysed specimens could ascend the shoots added for food and thus escape detection. However, after a trial had been in progress for five days it was most unusual to find any weevils showing signs of paralysis, either they had recovered or, much more likely, succumbed. All results are calculated from the number of weevils dead on the fifth day after each trial began.

Materials employed in preliminary trials are shown in Table I. All were diluted with china clay except the benzene hexachloride dusts, which had a carrier composed of 67 per cent. gypsum and 33 per cent. basic slag, and the 5·7 per cent. rotenone, which was a sample of undiluted, finely ground Lonchocarpus root as used to prepare the 1 per cent. rotenone (Lonchocarpus) dust. Lethane HE-60 contains 50 per cent. β-thiocyanoethyl esters of mixed fatty acids and Lethane 384 contains 50 per cent. β-butoxy-β′-thiocyanodiethyl ether. The Derris-Lethane contained 2 per cent. (w/w) Lethane HE-60 and 0·4 per cent. rotenone from Derris root containing 5·7 per cent. rotenone and 20·5 per cent. ether extractives. The 1 per cent. rotenone dusts were made up from Derris root of 1·9 per cent. rotenone content and 20·2 per cent. ether extractives and Lonchocarpus root of 5·7 per cent. rotenone content and 22·4 per cent. ether extractives. The D.D.T. contained approximately 75 per cent. *p*-*p*′ isomer and the benzene hexachloride about 10 per cent. gamma isomer.

There were five replicates, each cage containing 10 or 20 weevils.

Results.

From Table I it will be seen that only 5 and 10 per cent. D.N.O.C., 5 per cent. D.D.T. and 1 and 3 per cent. benzene hexachloride gave satisfactory kills. In view of past claims

for a 50 per cent. reduction in capped blossoms after using dusts of 0·15 and 0·36 per cent. rotenone the strength was raised to 1 per cent. (which is considered uneconomic) in order to give this substance a final test. It will be noted from the results that the necessity of balancing control against cost did not arise. Evidently the Apple Blossom Weevil is highly resistant to the action of rotenone, for only 83 per cent. were killed when the unadulterated ground root containing 5·7 per cent. rotenone was tested.

Further trials of a more detailed nature were carried out with D.N.O.C. dusts but even in the laboratory it became evident that this substance possessed considerable phytotoxic action at both strengths ; although very efficient in killing weevils it had to be rejected on this account. D.N.O.C. appeared also to stimulate oviposition, but instead of the eggs being laid inside the buds, they were deposited on the buds, shoots and sides of the lamp glasses.

Benzene hexachloride at 1 and 3 per cent. on a gypsum-slag base gave a complete kill when weevils and food were dusted, but the former appeared inferior against the weevils alone (Table II). These samples, the only ones available at the time, were much too heavy for use on top fruits and a further series of tests in 1945, when china clay was substituted as carrier, gave quite different results. In the later trials even at 5 per cent. only 58 per cent. mortality occurred when the weevils were dusted, whilst 51 per cent. died if placed on treated food. It is well known that the performance of certain insecticides can be improved by the selection of a suitable base and the available evidence suggests this is so when benzene hexachloride is combined with gypsum and slag. The resulting dust is, unfortunately, too heavy for use on trees. The differences in kill have also probably been influenced by the method of dusting, whereby an attempt was made to use equal volumes of dust for all tests. With a comparatively heavy base like gypsum-slag a larger quantity of the actual insecticide would be present than where the less weighty china clay was used.

Against weevils alone benzene hexachloride acted very rapidly, and after about sixteen hours the total number recorded as dead and paralysed remained constant until the tests ended. When the food only was dusted a steady increase in the number of dead and paralysed occurred until the sixth or seventh day at all the concentrations tested. Records were taken at too lengthy intervals for the effects to be fully illustrated by Fig. 1.

D.D.T. with a china clay base gave consistent results throughout the series of laboratory tests with an average kill of over 90 per cent. for a 5 per cent. dust. It acted more slowly than benzene hexachloride, as shown in Fig. 1.

When only weevils were dusted with D.D.T. approximately equal numbers developed paralysis during the first two twenty-four hour periods ; there were further small additions until the fifth

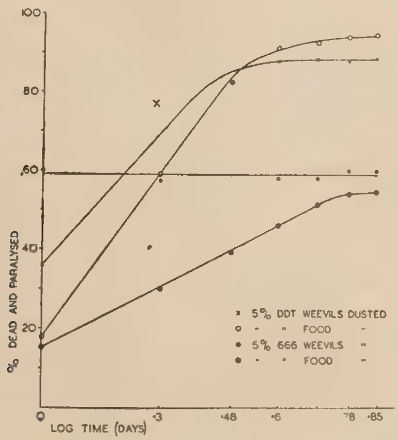

FIG. 1.

Time-mortality curves of Apple Blossom Weevil treated with 5 per cent. dusts of D.D.T. and benzene hexachloride (666).

TABLE II.

Detailed dusting trials against Apple Blossom Weevil.

Date started.	Treatment.		Total No. of weevils.	% Kill.
2/4/44 ..	1% Benzene hexachloride (666)* ..	W	100	27
	3% ,, ,, ,, ..	W	100	93
	5% D.D.T.	W	100	99
	Control		100	7
12/4/44 ..	3% Benzene hexachloride (666)* ..	W	100	96
	,, ,, ,, ..	F	100	97
	5% D.D.T.	W	100	95
	,, ...	F	100	78
	Control		200	0·5
14/3/45 ..	1% D.D.T.	W	150	8
	2% ,, ...	W	150	37
	3% ,, ...	W	150	59
	4% ,, ...	W	150	79
	5% ,, ...	W	150	89
	1% ,, ...	F	150	9
	2% ,, ...	F	150	36
	3% ,, ...	F	150	75
	4% ,, ...	F	150	79
	5% ,, ...	F	150	93
	1% Benzene hexachloride (666)† ..	W	150	5
	2% ,, ,, ,, ..	W	150	5
	3% ,, ,, ,, ..	W	150	17
	4% ,, ,, ,, ..	W	150	27
	5% ,, ,, ,, ..	W	150	58
	1% ,, ,, ,, ..	F	150	10
	2% ,, ,, ,, ..	F	150	15
	3% ,, ,, ,, ..	F	150	29
	4% ,, ,, ,, ..	F	150	46
	5% ,, ,, ,, ..	F	150	51
	Control		600	1

W=Weevils only dusted. F=Food only dusted.
*=Gypsum-slag base. †=China clay base.

There were five replicates in all the 1944 tests except the control (12/4/44) which contained ten. In 1945 each treatment was replicated six times, the control twenty-four times.

day, after which only dead and apparently healthy specimens remained in the cages. Fewer were affected during the first day if the food only was treated, but the mortality curve then rose more steeply for the second and third days than in the previous tests and no further effects were noted after the fifth or sixth days. These differences are undoubtedly due to the manner in which the weevils become contaminated with the toxic principle ; those adults treated with the dust would receive the maximum dose at the time of application apart from small particles which might be transferred from the body to the food in the course of feeding or movement and subsequently picked up by the same or other individuals. When clean weevils are liberated in cages containing dusted food some spend several hours on the lamp glasses before finding the food. This delay in coming into contact with D.D.T. partly explains why fewer become paralysed on the first day ; but having once found the shoots most of the weevils remain there, moving from bud to bud and feeding. In the course of their travels they probably pick up more D.D.T. than is normally deposited on dusted weevils, being in contact with a treated surface all the time ; hence the greater incidence of paralysis or death on the second and third days.

Mention has already been made of the results obtained when tests are carried out with weevils that have only recently matured. Table III gives the results obtained with 5 per cent. D.D.T. and 3 per cent. benzene hexachloride by dusting weevils only. There were usually

five replicate tests, but six of 5 per cent. D.D.T., 14/3/45, and three each of 3 per cent. benzene hexachloride on 30/3/45. After the tests in June 1944 one possible explanation appeared to be that the materials had lost their toxicity through keeping, but the 1945 results obtained with the same samples of dusts indicated that this was not so. Time has not permitted further investigation but it appears probable that the physiological condition of the insect differs before and after hibernation. In June the fat body is being built up as a source of nourishment during the quiescent period which lasts about eight months, whereas the spring period is one of rapid sexual maturation.

Table III.

Effects of dusting weevils before and after hibernation.

Date started.	Treatment.	Total No. of weevils.	% Kill.
12/4/44 ..	5% D.D.T.	100	95
27/6/44 ..	,, ...	100	0
14/3/45 ..	,, ...	150	89
12/4/44 ..	3% Benzene hexachloride*	100	96
27/6/44 ..	,, ,, ...	100	5
30/3/45 ..	,, ,, ...	60	67
27/6/44 ..	3% Benzene hexachloride†	100	0
30/3/45 ..	,, ,, ...	60	18

*=Gypsum-slag base. †=China clay base.

Laboratory spraying trials.

Weevils were collected and caged in the same way as for the dusting trials. The sprays consisted of D.D.T. suspensions in water prepared by diluting a paste containing D.D.T., china clay, sulphite lye and water. In tests where weevils were treated they were sprayed by means of the modified Tattersfield apparatus, 2 cc. of liquid being used for each batch of twenty. The food was treated by dipping it in the suspensions until thoroughly wetted, allowing the surplus liquid to drain off and the shoots to dry before being placed in the cages. There were three replicates of each spray treatment, four of the control.

Table IV.

Laboratory spraying trials with D.D.T., 1945.

Date started.	Concentration %		Total No. of weevils.	% Kill.
28/3/45	0·025	W	60	87
	0·05	W	60	100
	0·1	W	60	100
	0·025	F	60	95
	0·05	F	60	100
	0·1	F	60	100
	Control		80	0

W=Weevils only treated. F=Food only treated.

As will be seen from Table IV all concentrations gave very good results. The weevils sprayed with 0·1 per cent. D.D.T. were knocked down within sixteen hours, more than half being dead at the end of this period, and within forty hours those sprayed with 0·05 per cent. were all lying on their backs with only four remaining alive. By the third day only one living specimen was present in each batch of cages containing food dipped in 0·05 and 0·1 per cent. solutions.

To obtain some indication of the residual effect of D.D.T. another set of twenty weevils was added on April 2nd to each cage containing food dipped at 0·05 per cent. These were all dead by April 7th and the food had wilted badly, but controls kept under similar conditions lost only one weevil out of sixty. On April 9th a further twenty weevils were added to each cage containing the same dipped shoots, to which fresh untreated fruiting spurs were added as food ; 67 per cent. of these had died by April 18th, after which no increase in mortality occurred and the experiment ended on April 22nd.

These results have two possible explanations ; either the D.D.T. lost its toxicity after three weeks, or so much of the toxic principle had been transferred to the weevils that only a sub-lethal dose remained on the treated shoots. Failure to collect sufficient weevils at a later date prevented further investigations in 1945.

Field trials 1943.

Greenslade (1945) concluded from trials carried out in 1942 that hexachloroethane and β-napththol possessed repellent properties against the Apple Blossom Weevil. Each chemical was dissolved in benzene, emulsified, and applied at a concentration of 0·25 per cent. In addition, a temporary reduction in the adult population, noticed during biological studies, was considered due to the lethal action of a routine winter petroleum spray containing 5 per cent. oil. Further observations on the emergence of weevils from hibernation, however, showed that many arrived on the trees when the buds were too advanced for a winter petroleum wash to be used without fear of serious phytotoxic effect. It was therefore decided to use in 1943 an emulsion of a highly refined petroleum oil of the type suitable for orchard use in summer. This spray had often been recommended at 1 per cent. for controlling the Fruit Tree Red Spider during the summer months, but no information was available regarding maximum strengths permissible before the blossom period. Concentrations of 1, 2 and 3 per cent. were chosen in addition to the repellents described above. Two rows of Lane's growing in isolation and noted for annual heavy infestations were sprayed with a knapsack, the repellents being applied on April 3rd and the petroleum washes on April 6th. Blocks of 16 trees received each treatment, about eight gallons being needed to wet them thoroughly. Results were assessed by tapping alternate trees in each block before and after spraying. As the trees were small and possessed no loose bark the figures obtained represented total populations. No significant differences could be detected between the populations before and after spraying or between treated and control blocks. Counts of capped blossoms at petal fall confirmed these preliminary findings. Visual inspection of the trees during the week following treatment indicated that neither hexachloroethane nor β-naphthol at 0·05 per cent. possessed much deterrent effect, for pairs of weevils could be seen on the branches and an occasional individual was found feeding. Similar observations were made on the blocks receiving summer petroleum.

Notes on spray injury were taken. Slight scorching of the rosette leaves occurred on all treated trees except those sprayed with 1 per cent. petroleum, and though the most forward trusses grew away satisfactorily, damage was greater to the fruit buds that had not burst. Many of these, especially in the 3 per cent. petroleum block, failed to produce blossom trusses satisfactorily.

Field trials 1944.

Two dusts, 5 per cent. D.D.T. and 1 per cent. rotenone, were chosen for use in the field ; the former because it had given promising results in the laboratory and the latter to clear up once and for all whether rotenone possessed any marked toxic action against the Apple Blossom Weevil. Both were mixed with china clay, the rotenone being in the form of freshly ground Lonchocarpus root, containing 5·7 per cent. rotenone and 22·4 per cent. ether extractives. As has been mentioned before, the difficulty in obtaining sufficient weevils until shortly before egg laying begins in the field precludes the planning and execution of large scale trials based on the current year's laboratory results. In order to avoid twelve months delay the rotenone dust was included before preliminary tests had been completed.

East Malling, Kent.—The 5 per cent. D.D.T. was applied to 76 trees forming the central portion of a double row of Lane's Prince Albert, the end trees being left as controls. The

rotenone dust was used on $1\frac{1}{2}$ acres of a mixed plantation of 30-year-old Lane's and Newton Wonder with an equal area left untreated. Each dust was applied at 60 lb. per acre on April 8th, 13th and 20th. Biological observations on another plot of Lane's gave April 3rd as the beginning of the egg-laying period. It was intended to start dusting as soon as eggs were found, but unfavourable weather caused a few days delay. All dusts were applied under ideal conditions and no rain fell until April 16th, when 0·3 in. was recorded.

Results were assessed in the D.D.T. trial by counting the total number of trusses and capped blossoms on alternate trees. A previous sample of 1,000 trusses at the pink bud stage had averaged 5·6 blossoms per truss, hence the total number of blossoms could easily be calculated and much time saved by counting only trusses later on. Only Lane's were counted in the rotenone trial where the capped blossoms were counted from 200 trusses on each of the north, east, south and west sides of twelve trees selected from the central portions of the treated and control plots.

Table V shows that a practically complete control of the Apple Blossom Weevil was achieved with 5 per cent. D.D.T., whereas 1 per cent. rotenone gave an apparent reduction of about 50 per cent. in capped blossoms. Both plots were lightly infested in 1944.

TABLE V.

Field Trials, East Malling, 1944.

Treatment.	Mean % capped blossoms.	Treatment.	Mean % capped blossoms.
North Control ..	4·13	—	—
5% D.D.T. ..	0·02	1% Rotenone	4·96
South Control ..	6·62	Control	9·12

TABLE VI.

Field Trials, Little Baddow, 1944.

Block.	Treatment.	Mean % capped blossoms.
North	Control	17·8
North-Central ..	5% D.D.T.	3·0
South-Central ..	1% Rotenone	11·1
South	Atomized Pyrethrum	10·0

Little Baddow, Essex.—These experiments were carried out on cordon trees, consisting of Cox's Orange Pippin, with James Grieve as pollinator, and a few rows of Ellison's Orange. The plantation covered $4\frac{3}{4}$ acres with rows running north-south and divided into approximately four equal blocks by east-west gangways. Each inside block received dust at the rate of 70 lb. per acre on April 7th, 12th and 18th. The north block was left as a control and the south one was treated by the owner with a commercial, atomized Pyrethrum spray whenever an experimental dust was applied. Biological observations on a nearby farm gave April 3rd as the beginning of egg laying on Cox, but windy weather again delayed dusting for a few days. A light easterly breeze was blowing on all three dates, nevertheless a good cover was obtained and the drift did not spread to neighbouring blocks. Fine weather persisted for a considerable time afterwards and insufficient rain fell to affect the deposit. No injury occurred to the trees.

Records were taken from trees of the variety Cox. Counts were made of the total number of trusses and capped blossoms on twenty samples of five consecutive trees in a row, equally distributed over each block, except the south where sixteen samples were taken. Previous sampling had shown there were 5·2 blossoms per truss. The results, presented in Table VI, again demonstrate the efficiency of 5 per cent. D.D.T., but the layout makes it impossible to

draw any definite conclusions regarding 1 per cent. rotenone and atomized Pyrethrum. The reductions compared with the control may be real or due to a trend with a naturally lower infestation at the south end.

Consideration of the East Malling and Little Baddow results leaves no doubt as to the efficiency of 5 per cent. D.D.T. and eliminates rotenone as being ineffective, even at 1 per cent., which is above the maximum economic strength, bearing out the laboratory findings. Running simultaneously with these trials were biological studies (Dicker, 1946) which indicated that egg laying had practically ceased by April 19th. Thus any control was due entirely to the effects of the first two applications. The absence of replicates is an obvious objection to each layout, but was necessitated by the need to dust on three separate occasions and ensure that there would be as little interference as possible from drift. By good fortune the wind was always from the same quarter.

Large plots were also considered necessary because the weevil was known to move about freely among the trees and it was feared that any useful effects produced by the dusts might be masked in small plots by subsequent migration from untreated areas. Observations on the 5 per cent. D.D.T. trial at East Malling showed these fears to be unfounded, for the percentage of blossoms capped demonstrated a very sharp demarcation between the control and treated areas.

Field trials 1945.

As a result of the 1944 laboratory tests benzene hexachloride and D.D.T., both as 3 per cent. dusts with a carrier consisting of 12 per cent. gypsum and 88 per cent. china clay, were included in field trials in Kent and Essex. In addition a further trial was run at East Malling to compare 3 and 5 per cent. D.D.T. dusts, the latter being from the same sample as used in 1944.

Experience gained during the previous year allowed slight elaboration in the layout of plots. Replication was possible, based on the assumption that the wind would be from approximately the same direction each time a dust was applied. Brief descriptions of the layouts precede the results of each trial and a comprehensive discussion follows at the end of the paper.

East Malling, Kent.—Two rows of Lane's growing alone were used to compare the D.D.T. dusts. The strip was divided into seven equal sections, two being treated with each concentration of dust and three remaining as controls. Each dust was applied at 40-45 lb. per acre on March 17th and 23rd. Egg laying began on March 17th. The number of trusses and capped blossoms was counted on all trees except guards, of which eight were left between each treatment.

Table VII.

Field Trials, East Malling, 1945.

Treatment.	Mean % capped blossoms.	Treatment.	Mean % capped blossoms.
	—	East Control	23·0
3% D.D.T.	6·1	3% D.D.T.	22·0
5% D.D.T.	0·7	3% Benzene hexachloride	15·6
Control	16·8	West Control	43·3

In this trial, as will be seen from the left half of Table VII, both 3 and 5 per cent. D.D.T. reduced the attack, the latter being superior and achieving an almost complete control.

A second trial comparing 3 per cent. dusts of D.D.T. and benzene hexachloride was carried out in the mixed Lane's and Newton Wonder orchard used in 1944. Here replication was impossible due to the shape of the orchard and the prevailing wind. The plantation was divided into four blocks of $1\frac{1}{4}$ acres with the outside ones untreated ; 45 lb. per acre of each dust was applied on March 15th and 23rd. Cover was good and very little rain fell during the effective

period. Capped blossoms present in 100 trusses on each of the north, east, south and west sides of ten trees selected from the centre portion of each block are shown in the right half of Table VII. No conclusive results were obtained, though 3 per cent. benzene hexachloride appeared to halve the infestation.

Danbury, Essex.—Four blocks of thirteen-year-old Cox's with James Grieve as pollinator, each between two and three acres in extent were used to compare 3 per cent. dusts of D.D.T. and benzene hexachloride. From each block four plots containing 49 trees, covering approximately one-sixth of an acre, were chosen so that two were dusted and the others left untreated. Both dusts were applied at 70 lb. per acre on March 15th and 22nd. There were four replicates of each treatment and eight controls. The first egg was found on the variety, Cox, on March 14th.

TABLE VIII.

Field Trials, Danbury, 1945.

Treatment.	Mean % capped blossoms.
3% D.D.T.	1·7
3% Benzene hexachloride	5·0
Control	10·2

Eight trees of the variety Cox, from the centre of each plot, were chosen for records, and capped blossoms counted from 100 trusses on the north, east, south and west sides of each tree. At the pink bud stage a sample of 1,000 trusses had averaged 5·7 blossoms per truss. The results, presented in Table VIII, showed a significantly greater reduction in capped blossoms by 3 per cent. D.D.T. than by 3 per cent. benzene hexachloride.

A study of all the 1945 trials revealed that two applications of 5 per cent. D.D.T. at 40-50 lb. per acre gave an excellent control of the Apple Blossom Weevil, whilst 3 per cent. D.D.T. was more variable, increasing in effect when greater quantities of dust were applied to the trees. 3 per cent. benzene hexachloride failed to reduce capped blossoms by more than 50 per cent.

DISCUSSION OF FIELD TRIALS.

Of the various insecticides tested against the Apple Blossom Weevil, only two, D.D.T. and benzene hexachloride, have proved suitable for inclusion in field trials. A 5 per cent. D.D.T. dust has given consistently good results and from the figures obtained an adequate control may be expected from two applications of 40-45 lb. per acre applied at bud burst and again a week later. When the strength is reduced to 3 per cent. results are much more variable ; at East Malling in 1945 it was shown to be considerably less effective than a 5 per cent. dust in one trial and apparently ineffective in another, when applied twice at 40-45 lb. per acre, whilst in Essex good control was obtained by increasing the quantity of dust to 70 lb. per acre. There is thus some indication that kill is proportional to the quantity used ; but as 3 per cent. is bordering on the sub-lethal it cannot be recommended, for, from an economic viewpoint the greater quantities required and the reduced chances of success outweigh any slight additional cost of the more concentrated dust.

Benzene hexachloride at 3 per cent. is less effective than D.D.T. at the same strength when compared on a china clay base. It is true that it appeared to give better control in 1945 at East Malling, but more importance should be attached to the replicated Essex trial. A study of the results of laboratory tests would lead one to expect a performance inferior to D.D.T. at 5 per cent. also, though commercial control may be obtained. Further trials are necessary to evaluate these dusts when applied once and twice at 5 per cent.

Great difficulty has been experienced in devising layouts for field trials which allow of replication while at the same time taking sufficient precautions to prevent drift interfering

with other treated and control plots. Even during the calmest periods, which usually occur shortly after dawn and again in the evening, the dust cannot be confined to small plots but drifts through several adjacent rows, the use of screens being of doubtful value as so much passes over their tops. A further complication was introduced into the present trials by the necessity to dust thrice in 1944 and twice in 1945, with the possibility of a change in the direction of the wind when later applications were made. In addition, adult weevils were known to move freely from tree to tree during warm days, so that measures were necessary to guard against reinfestation of treated plots from adjacent untreated areas subsequent to dusting.

Bearing all these facts in mind it was decided to forgo replication in the 1944 experiments and dust large blocks of not less than an acre, leaving a comparable area untreated, the results being assessed by recording the percentage blossoms capped on selected trees in the central portion of each treated and control block. Replication would have involved large areas under these conditions and have led to further complications, for uniform infestations of the Apple Blossom Weevil are very localized.

The 1944 trial at East Malling with 5 per cent. D.D.T., on two rows of trees growing in isolation, permitted the use of smaller plots with a control on each side of the treated area. Records of capped blossoms taken on trees at the junction of control and treated plots showed a uniformly low infestation on all dusted trees whilst adjacent controls were much more heavily infested. Owing to the direction of the wind some drift settled on a few trees in one of the control plots, reducing the attack to the same order as throughout the treated area. These results demonstrate a freedom from secondary infestation under the conditions prevailing which may be attributed to the persistent effect of D.D.T. acting either as a repellent or a contact insecticide. The former appears unlikely, for no such repellent action was noted in laboratory trials. On the other hand, D.D.T. is comparatively slow in action—fresh cases of paralysis followed by death were noted in laboratory experiments up to four days after placing weevils on dusted food—and it would therefore seem possible for eggs to be laid by many weevils before paralysis set in, unless, as is suspected but not yet proved, contact with a toxic dose inhibits oviposition before the more usual external symptoms develop. Cragg (1945) has demonstrated a similar effect against the sheep blowfly and a somewhat analogous effect has been noted by the writers when last instar larvae of *Pieris brassicae* are placed on food dusted with 3 per cent. D.D.T. ; feeding ceases almost immediately yet paralysis and death may not take place for several days.

With the knowledge that migration of weevils would be unlikely to affect results, the 1945 trials were elaborated to include replication where the shape of the orchard permitted. A simple layout was still necessary as drift and a change of wind had to be considered. Preference was given to an orchard with its long axis facing the prevailing wind so that the dusted plots could be arranged more or less in a straight line, with controls adjoining on the windward side. By allowing adequate guard rows a variation of 90 degrees in the wind direction could be tolerated without fear of results being affected by drift ; and by transposing treated and control plots the same layout held good for a wind from the opposite direction. An alternative plan was also prepared in case the wind should blow from any other direction. Even after all these precautions had been taken the choice of plots to be dusted was governed by the wind direction when the first application was made. In all the trials described the wind remained relatively constant throughout the critical periods.

Such layouts require much orchard space ; as an illustration, the trial at Danbury in 1945 occupied ten acres, yet included only three acres actually under treatment, the remainder consisting of guard rows and areas contaminated by drift.

The above discussion brings out the difficulties confronting field workers when testing dusts on top fruits. Orthodox systems of randomizing blocks have to be modified to meet particular circumstances, and this in turn may have an undesirable effect in so far as complete statistical analysis of results is precluded due to lack of sufficient replications. The present work, however, was undertaken primarily to discover a means of controlling the Apple Blossom Weevil, so that large differences were needed between treatment and controls. The results obtained with a 5 per cent. D.D.T. dust are sufficiently obvious without recourse to complicated mathematical analysis.

SUMMARY.

Preliminary laboratory trials in which Apple Blossom Weevils and their food were dusted with 1 per cent. Lethane HE-60, 1 per cent. Lethane 384, 5 per cent. dinitro-*o*-*cyclo*hexyl-phenol, 1 per cent. rotenone (derived from both Derris and Lonchocarpus roots), 5 per cent. dinitro-*o*-cresol and 5 per cent. D.D.T. (dichlorodiphenyltrichloroethane), all with a china clay base, and 3 per cent. benzene hexachloride with a gypsum-slag base, indicated that only the last three possessed any marked toxic effect against this weevil.

Further laboratory trials, in which the weevils and the food were dusted separately, showed that at 5 per cent., with a china clay base, D.D.T. gave an average kill of 90 per cent., whilst benzene hexachloride killed 50-60 per cent. The latter at 3 per cent. with a gypsum-slag base gave kills ranging from 93-97 per cent. but was too heavy for efficient orchard dusting. D.N.O.C. (dinitro-*o*-cresol) proved too phytotoxic for further tests.

In field trials during 1943-45 a 5 per cent. D.D.T. dust applied at 40-45 lb. per acre at bud burst and a week later gave excellent control ; 3 per cent. D.D.T. was less effective with indications that control was proportional to the quantity of dust used. Benzene hexachloride at 3 per cent. proved inferior to D.D.T. at the same strength.

Difficulties of layout for dusting trials of top fruits are discussed and a simplified method found successful in the present trials is described.

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CHEMICAL CONTROL OF FRUIT FORMATION

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GROWTH substances, or auxins, affect fruit formation in different ways; this can be shown by considering the properties of a particular compound. For example, α-naphthalene acetamide produces parthenocarpic fruits in Ilex (Gardner and Marth, 1939), and it prevents apple fruits dropping from the tree prematurely (Gardner *et al.*, 1939). Attempts to produce parthenogenetic embryos with it have failed, but empty seeds have been formed in *Datura stramonium* and *Melandrium dioicum* (Overbeek *et al.*, 1941). Recently, however, it has been claimed that in Petunia, Tagetes, *Trifolium repens* and *Brassica oleracea*, α-N.A. will overcome self-incompatibility (Eyster, 1941).

To be able to overcome incompatibility by the application of a growth substance is as important to the fundamentals of incompatibility as it is to the practice of fruit-growing. Thus the experiments which I describe here were primarily designed and undertaken to explain this effect, but since some treatments caused parthenocarpy and stimulated seed formation, the observations were extended to include these.

At first sight the different effects of α-N.A. are confusing, and reports on other growth substances not only add to the confusion but sometimes conflict one with another (See Table VI). Therefore the published data have been collected and summarized from which generalizations can now be made that help to reconcile the discrepancies; at the same time, they indicate the kinds of fruit on which auxins may effectively be applied.

The effects of α-N.A. in *Prunus avium* have already been described in a short note (Lewis, 1942); the results are given here in more detail with results in *Prunus domestica* and *Oenothera organensis*. These plants are all self-incompatible, but the degree of incompatibility varies, being absolute in Oenothera and *P. avium* and only partial in some varieties of *P. domestica*.

Incompatibility is genetically controlled, and is due to the pollen-tubes failing to reach the ovary before the flower withers or abscisses; fertilization fails to take place and the ovary and ovules fail to develop. To determine the action of α-N.A. its effect on (1) the pollen-tubes, (2) the abscission process of the flower and style and (3) fruit and seed formation with and without pollen must be studied.

POLLEN-TUBE GROWTH AND ABSCISSION.

METHODS.

In *Prunus avium* and *Prunus domestica* a 20 parts per million aqueous solution of α-N.A. was applied to the flowers so that a large drop remained on the ovary and style. One drop was applied each day from the start of the treatment until the style or flower abscissed. In Oenothera the aqueous solution was poured into the long calyx tube. Other treatments were given to Oenothera with a 1 per cent. emulsion of α-N.A. in lanolin. In one set of experiments the lanolin emulsion was smeared on the upper part of the ovary and the lower part of the calyx tube (*ovary smear*). In other experiments the lanolin was smeared on the style for a distance of 20 mm. (*style smear*). The upper limit of the style smear was, in some experiments immediately below the stigma and in others 15 mm. below.

The method of pollen-tube examination in *P. avium* and *P. domestica* was as follows: Styles were fixed in 3 : 1 alcohol-acetic acid solution and stored in 50 per cent. alcohol. Before sectioning on a freezing microtome the styles were transferred to water. Longitudinal sections 20μ thick were cut. The stain used was light green/acid fuchsin (2 c.c. 1 per cent. green aq., 2 c.c. 1 per cent. fuchsin aq., 10 c.c. glycerine, 40 c.c. lactic acid, 46 c.c. distilled water).

For Oenothera the central conducting tissue was dissected from the style. This tissue was lightly squashed on a slide and stained with a 1 per cent. solution of cotton blue in lacto-phenol.

RESULTS.

Prunus avium.—An aqueous solution of α-N.A. applied to the flowers delayed the abscission of the style by two days (Lewis, 1942). Unpollinated or self-pollinated flowers lost their styles

after four days, and this period was prolonged to six days by α-N.A. Flowers that had been pollinated with compatible pollen lost their styles after six days, and this was prolonged to seven days by α-N.A. (Plate I, Figs. 1 and 2). Treatment with α-N.A., however, did not affect the growth of compatible pollen tubes and its effect on the incompatible tubes was slightly to retard their growth (see Table I).

TABLE I.

Mean length in mm. of pollen tubes in Prunus avium *self-pollinated.*

Treatment.	2 days.	4 and 6 days.
1 Control	4·8	7·2
2 Water	5·3	7·8
3 α-N.A.	5·1	5·8

Value of t for difference between 1 and 3 = 2·73, p = 0·05–0·02

In Table I the measurements made at four and six days after pollination are combined because growth ceased on the fourth day. At two days the treatment showed no effect on the pollen tubes, but at four days the α-N.A. treated tubes were significantly shorter than either the control or the water-treated ones ; this is shown by the high value of t.

It is not quite clear how α-N.A. stops the growth of incompatible tubes before their normal time while having no effect on compatible tubes. It is known, however, from the results reported later on Oenothera, that a high concentration of α-N.A. is lethal to pollen-tube growth. Compatible tubes with their higher growth rate might pass through the lower part of the style (where the drops of α-N.A. are applied) before a lethal concentration had accumulated, whilst incompatible tubes, arriving two days later, would meet a higher concentration due to the two additional days treatment.

Prunus domestica.—The four varieties selected for treatment differed in their self incompatibility and general fruitfulness. Pond's Seedling is fully self-incompatible, while Cambridge Gage, Old Greengage C and Early Rivers are only partially self-incompatible, 2 to 3 per cent. of the pollinated flowers forming fruits (Crane and Brown, 1939).

As in cherries, α-N.A. treatment delayed the abscission of the style by two to three days and had no effect on the pollen tubes, at least during the first four days of growth (see Table II). It therefore did not affect incompatibility. But there are differences between plums and cherries as regards their style abscission which are independent of treatment. The normal life of the style and the effect of compatible pollination are different ; in plums the style, whether pollinated with compatible or incompatible pollen or not pollinated at all, abscisses after five or seven days, according to the variety, whereas in cherries compatible pollination delays the abscission by two days, i.e. from four to six days. Climatic conditions also affect the life of the style, and the environment of the greenhouse in which the experiments were carried out probably favoured early abscission.

The varieties differ in the abscission time of the style ; this is five days in Pond's Seedling, whilst in the Gages and Early Rivers it is seven days. Furthermore, the length of the style varies, being 14 mm. in Pond's Seedling, 12 mm. in the Gages, and 8 mm. in Early Rivers. Thus, in Pond's Seedling, pollen tubes have not only the greatest distance to grow but have the least time available for this growth. The length and life of the style, the selfed fruit set and the observed pollen-tube growth are given in Table III. It is apparent from this that in these particular cases a shorter style which drops late is associated with the partial self-incompatibility found in the Gages and Early Rivers.

It is known that pollen tubes which are fully incompatible stop growing completely after four days, and no shortening of the length and increasing the life of the style should have any effect on these pollen tubes. In partially self-incompatible varieties, such as Early Rivers, apart from the fully incompatible tubes there is a small proportion—probably less than 1 in 10,000—that have the power to achieve fertilization under favourable conditions. For

example, by pollinating young flowers the percentage of fruit set in these varieties is higher than with normal pollinations (Lewis, unpub.). It is probable that varieties, such as Pond's Seedling that set no fruits on selfing also have this small proportion of partially incompatible tubes, but the longer style might prevent their functioning.

TABLE II.

Mean length of pollen tubes four days after pollination and the number of days between flower opening and the abscission of the style.

Variety.	Selfed.		Crossed.		Selfed and α-N.A.		No pollen. No auxin.		α-N.A.	
	mm.	days.	mm.	days.	mm.	days.	mm.	days.	mm.	days.
Pond's Seedling ..	5·9	5	14·0	5	5·8	8	—	—	—	—
Cambridge Gage ..	6·8	7	12·0	7	5·3	10	—	—	—	—
Old Greengage (C)	7·7	7	12·0	7	7·8	10	—	7	—	9
Early Rivers ..	5·6	7	8·0	7	6·1	8	—	—	—	—

TABLE III.

Relationship between length and life of the style, pollen-tube growth and fruit set in plums.

Variety.	Length of style. mm.	Life of style. Days.	Pollen-tube growth per day. Observed.	Necessary.	% Selfed fruit set (Crane and Brown, 1939).
Pond's Seedling ..	14	5	1·4	2·8	0·0
Cambridge Gage ..	12	7	1·7	1·7	1·0
Old Greengage (C)	12	7	1·9	1·7	2·8
Early Rivers ..	8	7	1·4	1·1	3·4

NOTE.—The pollen-tube growth is calculated as follows:
1. *Observed*, is the mean of the observed growth in 4 days.
2. *Necessary*, is the length of the style divided by the number of days available for growth of pollen tubes.

Quite distinct from incompatibility is the general fruitfulness of these varieties. Crane and Brown (1939) have shown that varieties which are notoriously bad croppers and are self-incompatible set very good crops when they are efficiently pollinated. Of the varieties examined here, Pond's Seedling and Early Rivers are reliable croppers, but the two Gages are erratic, producing a good crop in some years and a poor crop in others. Dorsey (1919) found that in American plums slow pollen-tube growth, rapid disintegration of the stigma and early abscission of the style are causes of unfruitfulness. It was thought that the erratic bearing of Gage plums might be due to styles which absciss sooner than those of other varieties, thus leaving a smaller margin of safety for effective pollination. The observations, however, show differences which are contrary to these expectations, and other causes, therefore, must be looked for to explain the erratic bearing of these varieties.

Oenothera organensis.—Drops of the aqueous solution of α-N.A., placed in the bottom of the calyx tube, affected neither the pollen tubes nor the abscission of the style.

Smearing the ovary and lower part of the calyx tube with 1 per cent. emulsion in lanolin delayed the abscission of the style but not to the same extent as in Prunus (see Table IV). The emulsion was applied to the ovary from four days before, up to the time the flower opened, but the time of treatment was immaterial. Incompatible tubes were not affected by the treatment, but a negative effect was expected, since these tubes did not grow more than 45 mm. and the treated area of the style was more than 150 mm. below the stigma. Pollen tubes in incompatible crosses could not be measured because they had entered the ovary some days before abscission. There were some adverse effects on compatible tubes which passed through

the treated area of the style, because not more than half the normal number of fertilized seeds were produced in a capsule after treatment and compatible pollination.

TABLE IV.

Times of abscission of the style in Oenothera organensis *and means of the longest pollen tube in each style, showing the effect of* 1 *per cent. emulsion of α-N.A. when applied at the base of the calyx tube.*

Treatment.	Pollination.	No. of flowers.	Days to abscission.	Mean length pollen-tubes.
None.	None.	4	3·5	—
None.	Selfed.	4	3·2	42·6
None.	Crossed.	3	3·3	—
1% α-N.A.	None.	3	4·0	—
,,	Selfed.	7	3·7	49·5
,,	Crossed.	2	4·5	—

Smearing the upper part of the style with 1 per cent. emulsion had a profound effect on the pollen tubes (see Table V). Incompatible tubes grew to the same length after treatment as in the controls, but the ends of the treated tubes had nearly always become swollen or had burst. The effect on compatible tubes was even more striking, for instead of the tubes reaching 20 mm. in length in four hours they stopped at 4 to 5 mm. and the ends burst.

Branched tubes and the emission of more than one tube from a pollen grain was another very frequent abnormality found in the treated styles. Similar abnormalities have been recorded in untreated styles of other plants, but they have always been associated with polyploidy, e.g. the autotetraploid pear variety Fertility, and the variety Beurré Bedford which, although a diploid, produces polyploid pollen grains (Thomas, 1942) ; also in hexaploid Rubus species and tetraploid *Lycopersicum esculentum* (Modlibowska, unpub.).

In these style smears of Oenothera the time and place of application of the emulsion was varied slightly (see Table V). In one experiment the α-N.A. was applied 15 hours before pollination and in another, only one hour before. In the one-hour experiment some of the styles were treated from immediately below the stigma to 20 mm. below, others received α-N.A. from 15 mm. to 35 mm. below the stigma. In all cases, the effects were the same, showing that α-N.A. is absorbed and transported in the style very rapidly. The rate of transport must be as great as 15 mm. per hour, and is probably even faster. The only other data on this point are for the rate of transport of auxin in the Avena coleoptile ; this is estimated at 15 mm. per hour (Went and Thimann, 1937).

TABLE V.

Mean lengths of pollen tubes in compatible and incompatible pollinations in Oenothera, with and without α-N.A.

	Control (Lanolin).		α-N.A. 15 hours before: At stigma.		α-N.A. 1 hour before : At stigma.		α-N.A. 1 hour before : 15-35 mm. below.	
	Comp.	Incomp.	Comp.	Incomp.	Comp.	Incomp.	Comp.	Incomp.
4 hours ..	19·3	3·5	3·6*	3·0*	3·8*	3·5†	4·0*	3·7*
	20·0	4·2	3·8*	3·1*	4·0*	—	4·5*	—
	—	—	—	—	4·4*	—	—	—
	—	—	—	—	4·5*	—	—	—
24 hours ..	140·0	3·4	3·6*	3·0*	4·7*	3·0†	7·0*	—

NOTE.—The 1 per cent. emulsion was applied either 15 hours or 1 hour before pollination on a part of the style 20 mm. long. The treated part of the style was either from immediately below the stigma to 20 mm. below or from 15 mm. to 35 mm. below.

* = burst tubes † = swollen tubes.

PARTHENOCARPY AND SEED FORMATION.

In cherries, α-N.A. treatment, either as an aqueous solution or a lanolin smear, without compatible pollination, did not stimulate fruit formation. Similar treatments given to plums and to the pear varieties Conference, Fertility and Doyenné du Comice also had no effect on fruit formation. But in Oenothera the ovary smear treatment caused fruit to develop in every treated flower (see Plate I, Fig. 3). The ovary started to swell one to two days after treatment, and the swelling was sometimes so rapid that the ovary prematurely burst along the sutures, exposing the ovules. This treatment was equally effective if it was done as late as five days after the flower had withered.

The ovules swelled like normally fertilized ones and, when ripe, the seeds were as long as the normal but a little thinner. These artificially stimulated seeds, however, were empty; 24 capsules contained approximately 8,000 seeds, 300 of which were dissected, but only one contained an embryo and this failed to germinate. This embryo came from a tetraploid plant and it was probably a parthenogenetic diploid. The remainder of the seeds were sown but they did not germinate.

In Datura and Melandrium, Overbeek *et al.* (1941) found similar empty seeds after treating the ovary with naphthalene acetic acid. In these plants, however, smearing the outside of the ovary caused ovary swelling without ovule development; it was necessary to inject the substance into the ovary to obtain ovule swelling. As in Oenothera, these seeds did not germinate.

The published data on the stimulation of fruit development with chemicals are summarized in Table VI. The methods of application and the concentrations used have been omitted, since neither of these factors appears to have any general significance. Some substances are undoubtedly more active than others, but the success of any treatment depends mainly on the kind of fruit treated. If the fruit has many seeds, as the Cucurbits, tomato or Oenothera, then parthenocarpic fruits are stimulated. If the fruit has one or only few seeds, as in cherries and plums, then parthenocarpic fruits are not formed. Fruits containing seeds without embryos are frequently formed after normal pollination in Prunus but, as shown by Crane and Lawrence (1929), fertilization occurs and the embryo aborts subsequently. Moreover, Crane and Brown (1939) have shown that seedless fruits of the Myrobalan plum arising in this way are smaller than the seeded ones. It is possible that the addition of a growth substance to these seedless fruits might increase their size.

Some species, such as *Pyrus communis* and *Pyrus malus*, appear to be borderline cases. They have a maximum seed content of ten per fruit. Most attempts to produce parthenocarpic fruits in these species have failed, but a single success has been reported for both. It is known that different varieties of apples and pears have different potentialities for parthenocarpic development, and the varieties that have parthenocarpic tendencies are probably those which can be stimulated to form fruits with growth substances. Pear varieties known to produce seedless fruits without pollination are Conference and Fertility (frost damage alone will produce seedless fruits without pollination in Conference), but these varieties have failed to respond to applications of α-N.A. both as an aqueous spray and a lanolin paste. Possibly further trials with other substances will yield positive results in these varieties.

Gustafson (1941) has related in species of Solanum and Cucurbita the ability to produce parthenocarpic fruits by chemicals to the same degree as that by natural auxin in the normal ovary; a high natural auxin content was correlated with a greater parthenocarpic tendency. Whether single-seeded ovaries in general have less auxin than many-seeded ones is not known, but this would be a possible explanation. It is known, however, that there are two main stimuli to fruit formation: (1) the pollen tubes as they enter the ovary, and (2) the developing ovules (Gustafson, 1942). The observations of Tukey (1936) are of interest in this respect. He found that in peaches asymmetry of the fruit was caused by an effect of the developing ovule. The larger side of the fruit was always the side on which the developed ovule was attached. This may be an extreme case of localization of auxin. In many-seeded fruits the pollen tubes may give a greater stimulus than the ovules, and since pollen contains much auxin it is reasonable to assume that artificial growth substances could replace it in stimulating fruit formation. In single-seeded fruits the stimulation from the pollen tubes may be insignificant and the developing embryo may have an overriding effect; thus chemicals would not be effective.

TABLE VI.

(1) *Species in which growth substances have stimulated the development of parthenocarpic fruits.*

Species.	Auxins used.*	Authors.
Antirrhinum *sp.*	2, 5, 1, 4	Gustafson, 1936
Agapanthus *sp.*	1	Gustafson, 1936
Begonia *sp.*	1	Gustafson, 1936
Capsicum annuum	1, 4, 14, 8	Gustafson, 1936 Wong, 1938
Citrullus vulgaris	1, 4, 8	Wong, 1938 Gustafson, 1941
Crinum americanum	8	Hubert & Manton, 1939
,, *longifolium*	8	Wong, 1941
Cucumis melo	1	
,, *sativa*	1, 8, 14	Gustafson, 1938 Wong, 1938
Cucurbita maxima	1	Oinone, 1938 Gustafson, 1941 Wong, 1941
,, *moschata*	4, 8	Gustafson, 1936 Wong, 1941
,, *pepo*	1, 4, 8	Sereisky, 1939 Hubert & Manton, 1939 Gustafson, 1941
Cymbidium *sp.*	8	Hubert & Manton, 1939
Datura stramonium	4, 8	Overbeek *et al.*, 1941
Digitalis purpurea	1	Sereisky, 1939
Fragaria *sp.*	1 1 7	Gardner & Marth, 1937 Wong, 1941 Swarbrick, 1943
Fuchsia hybrida	1	Oleson, 1938 (Gustafson, 1942)

Species.	Auxins used.*	Authors.
Gladiolus *sp.*	1, 8	Hagemann, 1937 Hubert & Manton, 1937
Ilex opaca	1, 2, 4, 8, 10	Gardner & Marth, 1939
Lycopersicum esculentum	1, 2, 4, 5, 7, 8, 9, 14, 16	Gustafson, 1940 Howlett, 1940 Strong, 1941 Swarbrick, 1945
Melandrium dioicum	1, 4, 8	Overbeek *et al.*, 1941
Nicotiana *sp.*	14	Gustafson, 1938
Oenothera organensis	10	Lewis, unpublished
Oncidium longipes	8	Hubert & Manton, 1939
Petunia hybrida	1, 2, 4	Gustafson, 1936
Primula hortensis	(?)	Oleson, 1938 (Gustafson, 1942)
Pyrus communis	1	Sereisky, 1938 Swarbrick, 1945
Salpiglossis variabilis	1, 2, 4	Gustafson, 1936
Solanum melongena	1, 6, 14	Oinone, 1938
Vitis vinifera	1, 16	Oinone, 1938
Zephyranthes canina	1	Gustafson, 1936

* For list of auxins see Table VIA.

TABLE VI (continued).

(2) *Species in which growth substances have failed to stimulate the development of parthenocarpic fruits.*

Species.	Auxins used.*	Authors.
Carya pecan	1, 4	Smith, 1944
Phoenix dactylifera	1, 4, 8	Nixon & Gardner, 1939
Prunus avium	10	Lewis, unpublished
,, *domestica*	10	Lewis, unpublished
Pyrus communis	10	Lewis, unpublished (Gustafson, 1938)
,, *malus*	1, 10, 11, 12, 13, 14	Gardner *et al.*, 1939 Gustafson, 1938 Hilton, 1944 Swarbrick, 1945

* For list of auxins see Table VIA.

TABLE VIA.

Growth substances referred to in Table VI.

1. Indole acetic acid.
2. β-indole propionic acid.
3. Indole-3-butyric acid.
4. α-indole butyric acid.
5. Phenylacetic acid.
6. Pyrole-α-carboxylic acid.
7. β-naphthoxyacetic acid.
8. α-naphthalene acetic acid.
9. 2 : 4-dichlorophenoxypropionic acid.
10. α-naphthalene acetamide.
11. Methyl-naphthalene acetate.
12. Ethyl-naphthalene acetate.
13. Na,P,Ca and NH_4 salts of naphthalene acetic acid.
14. K-indole acetate.
15. Na-naphthol sulphonate.
16. Oestrone.

DISCUSSION.

The property of α-N.A. to delay the abscission process in plum and cherry styles has been observed previously in the pedicels of Ilex flowers and in the petioles of Phaseolus leaves. In apples, α-N.A. delays the abscission of the mature fruit but does not affect that of the flower or of the young fruits in midsummer, the June drop. This difference has been shown to be due to a fundamental difference in the nature of the abscission. Flowers and immature fruits absciss by means of a specialized layer of cells formed by rapid cell division before abscission, whereas abscission of the mature fruit results from a change in the walls of pre-existing cells (MacDaniels, 1936). Plum and cherry styles absciss in the same way as the mature apple fruits do. Starch accumulates below the future abscission line and the tissue above it is starved ; later, the cell walls between these two areas decompose. How α-N.A. delays this process is not clear. Kraus and Mitchell (1939) have shown that α-N.A. results in a mobilization of solid materials at the place of application ; this may stop starch accumulating before abscission. The delaying effect of compatible pollination on abscission in cherries is also probably an auxin effect, since pollen contains a high concentration of auxin.

The effect of α-N.A. on self-incompatibility in Trifolium, Tagetes, etc. reported by Eyster (1941) can now be explained. Incompatibility involves many different and highly specific reactions between the pollen and the styles, so that a single substance which will counteract these reactions would be affecting something fundamental to the whole process. Eyster stated that α-N.A. made the slow growing incompatible pollen tubes grow faster. The only effect on pollen tubes found in the three species tested by the present writer was the complete inhibition of both compatible and incompatible tubes by a high concentration. Can the other effects of α-N.A.—abscission delay and parthenocarpy—exert this effect on incompatibility indirectly ?

A delay in the style abscission by two days would give a correspondingly longer period for the slow growing tubes to reach the ovary. In plants where the tubes are inhibited strongly in the upper part of the style, as in *Prunus avium* and Oenothera, no effect can be expected ; but in plants with a weaker incompatibility inhibition the extra time might bring about self-compatibility. In varieties of *Prunus domestica*, however, which normally show partial self-compatibility, α-N.A. had no effect.

The formation of seeds in Oenothera as the result of α-N.A. treatment gave the impression that the plant had become self-compatible, until the seeds were examined and found to be empty. It would be of interest to know whether the seeds of Trifolium and Tagetes germinated.

ACKNOWLEDGMENTS.

The author is indebted to Mr. M. B. Crane for much useful criticism and advice and to Dr. I. Modlibowska for a summary of the literature on which Table VI is based.

SUMMARY.

Growth-substances (auxins) affect fruit development, both directly by inducing parthenocarpy, and indirectly by affecting abscission processes. To determine which of these effects operates in different kinds of fruits an examination was made of the action of α-naphthalene acetamide on the processes leading to fruit development in *Prunus avium*, *Prunus domestica*, *Pyrus communis* and *Oenothera organensis*.

An aqueous solution (20 p.p.m.) of α-N.A., when applied to the styles of the Prunus species and Oenothera, delayed the abscission of the style by two to three days, i.e. approximately 30 per cent. of the lifetime of the style. It had no effect on compatible pollen tubes and none on incompatible tubes in *Prunus domestica* and *Oenothera organensis* ; but it had an indirect effect of slightly retarding the incompatible tubes of *Prunus avium*. It did not stimulate parthenocarpy in any of these species.

A 1 per cent. emulsion of α-N.A. in lanolin, when applied to the upper part of the style, caused both incompatible and compatible pollen tubes to swell and burst. This effect was used to measure the rate of transport of growth-substance in the style ; it was at least 15 mm.

per hour. When applied to the ovary of *Oenothera organensis* with incompatible pollen or without pollination, it delayed abscission of the style and stimulated parthenocarpy and the formation of empty seeds, thus making the plant appear to be self-compatible.

From these results and from the relevant published data it can be concluded that (1) parthenocarpy can be induced by growth-substances without pollination in many-seeded fruits only, (2) that the only type of abscission process that can be affected is one that is the result of a change in the walls of existing cells and not the result of rapid cell division. The type of abscission that is susceptible to treatment is that found in the style and the mature fruit, but not the abscission causing premature flower drop and the so-called June drop of fruits.

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PLATE I.

FIGS. 1 and 2.

Longitudinal sections through the lower ends of cherry styles, 4 days after flower opening, showing that α-naphthalene acetamide delays the abscission of the style.

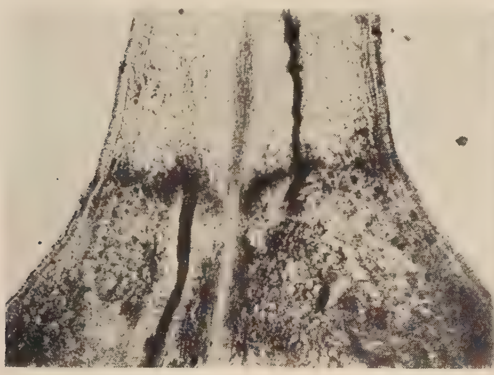

FIG. 1.

Untreated; the dark line running across the style is due to an accumulation of starch which precedes abscission.

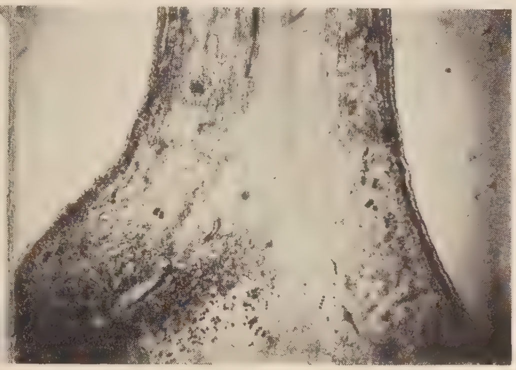

FIG. 2.

Treated with aqueous α-N.A.; the abscission line has not developed.

FIG. 3.

Capsules of *Oenothera organensis*: Left, pollinated untreated; middle, unpollinated treated with 1 per cent. α-N.A. in lanolin; right, unpollinated untreated.

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SIMPLIFICATIONS OF THE ROACH METHOD OF DIAGNOSTIC PLANT INJECTION

By WINIFRED O. ROBERTS

Plant injection methods have already been used successfully for the diagnosis of mineral deficiency in many parts of the world (Roach, 1939; Roach and Roberts, 1945), but they might be used much more widely if they could be simplified. Some of the drawbacks to their employment are these: the special glass tubes and other apparatus required are not always easily obtained, especially in remote parts overseas, where the methods are likely to be of immense value; a considerable degree of manipulative skill is necessary both for constructing the apparatus and for carrying out the injections; both wind and rain tend to interfere with the present methods; and the creeping of the test solution along a hairy leaf stalk is troublesome unless its base is painted with vaseline. Methods were therefore sought in order to overcome these difficulties and the two now to be described have given promising results in exploratory trials.

I.—The thread method of injection.

This is a "solid" injection in miniature. Very soft white stranded cotton thread, of the type used for household darning and consisting of four to six strands which can be separated, is soaked in the various test solutions and then dried. As a result solid particles of the substances required are deposited on the strands composing the thread. Supplies of each type of impregnated thread are kept in separate marked envelopes or other containers. Steel darning needles, of the fine, "slender", long-eyed type used for darning silk stockings, are employed to introduce short lengths of the thread into the plant tissue. Experience soon teaches how many strands of the impregnated thread are needed for any particular type of tissue.

The needle, carrying the thread double, is carefully pushed through the part of the plant selected for injection and the thread is drawn after it. The thread is cut on each side to leave a short length in the plant tissue. The mode of operation is illustrated in Fig. 1. It will be evident that by this method a small portion of the impregnated thread will remain in intimate contact with the tissue through which it passes and thus the solid reagent, after solution, can diffuse into the cells.

The method described is most useful for leaf-stalk and shoot tip injection. Interveinal injection of the leaf lamina may also be possible if great care is taken to damage the tissue as little as possible, though up to the present only the distribution of dye (1 per cent. acid fuchsin) has been studied by this method.

Leaves, leaf-stalks and shoots of Bramley's Seedling apple have been injected by means of thread soaked in 1 per cent. acid fuchsin to determine the distribution of the absorbed dye, in order to reveal the regions in which to expect a response when nutrients are injected in a similar manner. The results of such trials are illustrated in Fig. 1.

In preliminary tests with the thread injection method on leaf stalks, responses were obtained in late May on apple trees known to be deficient in iron. Thread soaked in 10 per cent. $FeSO_4$ + 0·1 per cent. H_2SO_4 caused damage, but thread soaked in 1 per cent. $FeSO_4$ + 0·1 per cent. H_2SO_4 caused no damage and gave definite responses. Apple trees known to be deficient in manganese gave responses to similar thread injections with 1 per cent. and 0·5 per cent. manganese sulphate.

II.—The pad method of injection.

Tufts of cotton wool are soaked in the test solutions to be used, lightly squeezed and kept in labelled, corked specimen tubes. Short lengths, about ¼ in. wide, are cut from a roll of new insulating tape, or plain surgical rubber plaster, and lightly stuck on the back of the left hand ready for use. The selected leaf is cut off clean at the base of the petiole with a razor blade of the Ever-Ready type (i.e. the type with only one cutting edge); a small pad of the impregnated

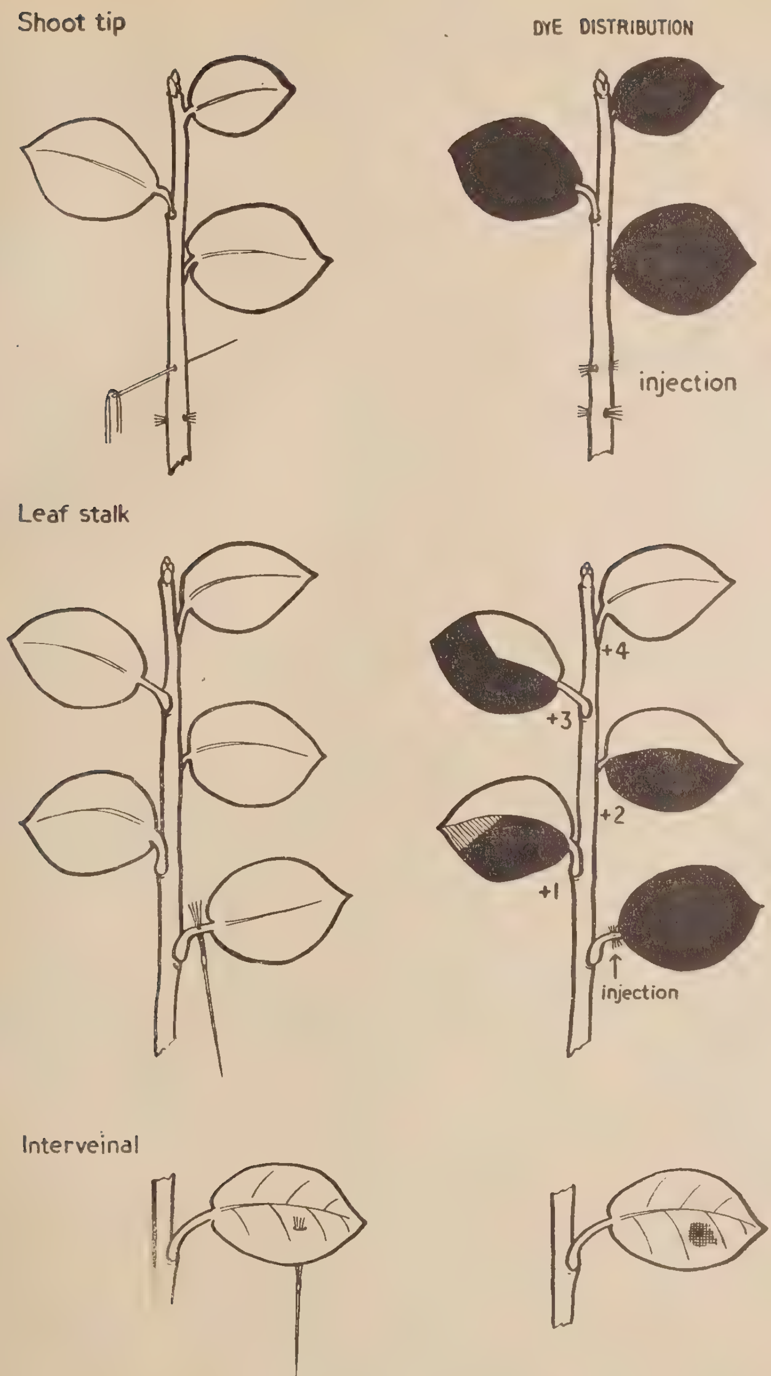

FIG. 1.

Diagrams showing the results of injecting a shoot tip, a petiole and a lamina of Bramley's Seedling apple with fuchsin by the thread method.

moist cotton wool is extracted from the desired specimen tube with a pair of forceps, placed on the cut surface and bound in position with a piece of the adhesive tape, as illustrated in Fig. 2. The advantages of this method are that the materials are easily obtainable and the manipulation simple; neither wind nor rain can interfere with the experiment.

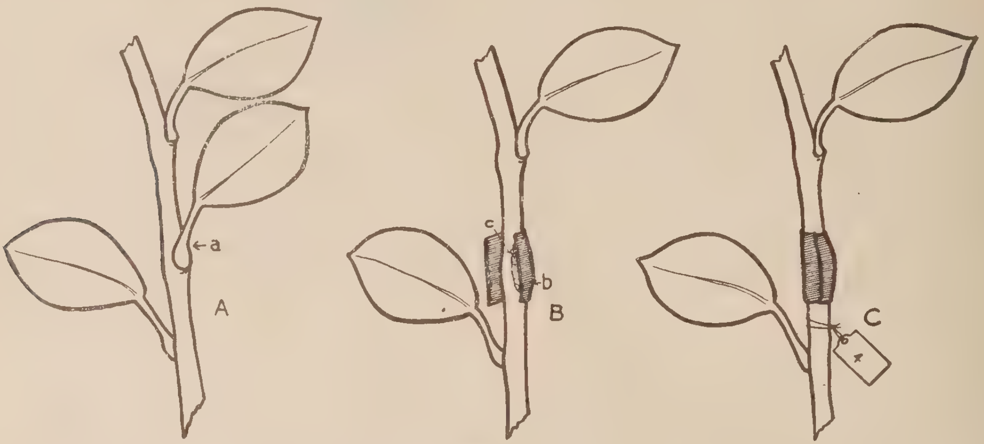

FIG. 2.

The pad injection method illustrated. In A, the base of the petiole of the leaf to be removed by a clean vertical cut is indicated at a. In B, c is the cotton wool pad containing the test-solution; b is the adhesive plaster. In C the operation is seen completed and labelled with reference number.

Trials have shown that the distribution of dye following the pad method of injection is identical with that obtained by the Roach "tube" method.

An exploratory trial of the pad injection method was carried out in late June on a chlorotic Hydrangea known to be deficient in iron. Four concentrations of ferrous sulphate were used: 10%, 5%, 1% and 0·5%, 0·1% H_2SO_4 being added to each to prevent precipitation. Each injection was repeated four times. Both 10% and 5% concentrations caused damage, but responses were obtained in five days from all of the 1% and the 0·5% solutions. The 1% concentration gave the strongest responses. (See Fig. 1, Plate I.)

A preliminary comparison of the tube, thread and pad methods of injection was made with quinces in July, 1945. A row of quince stocks in the stool beds showed severe chlorosis. On many shoots the chlorosis was in the lower leaves only, the top ones being green or partly green. It was therefore difficult to decide from symptoms alone whether the deficiency was that of iron, manganese or a combination of both. In consequence quadruplicate injections with ferrous and manganese sulphates, at different concentrations, were performed on these plants. The first was carried out by cutting off a lamina and bending the leaf stalk so as to immerse the cut end under the surface of the liquid held in a small tube held in position by a piece of lead wire attached to it (see Roach and Roberts, 1945, p. 7). In the second method the impregnated cotton thread passed through the leaf stalk but the lamina was not removed. In the third method the leaf was cut off close to the stem and the impregnated cotton pad placed on the cut. The responses as indicated by a development of green colour in parts of the leaves above and below the injection point, are shown in Table I.

The results of all three methods suggest that there was a combined deficiency of iron and manganese and that for quince, 1 and 0·5 per cent. concentrations of ferrous and manganese sulphates are the most suitable for both thread and pad methods of injection. The results also suggest that the two new methods are worth testing further in comparison with the tube method.

A quince shoot showing a response to a 1 per cent. $FeSO_4$ thread injection through a petiole is shown in Fig. 2, Plate I.

TABLE I.

A. TUBE METHOD.

$FeSO_4$ 0·025% + 0·025% H_2SO_4	$MnSO_4$ 0·025% + 0·025% H_2SO_4
· · · +	· · + +

B. THREAD METHOD.

$FeSO_4$ + 0·1% H_2SO_4						$MnSO_4$ + 0·1% H_2SO_4					
50%	25%	10%	1%	0·5%	0·1%	50%	25%	10%	1%	0·5%	0·1%
dd++	ddd+	ddd+	··++	·+++	····	dddd	dddd	d··+	··++	····	····

C. PAD METHOD.

$FeSO_4$ + 0·1% H_2SO_4			$MnSO_4$ + 0·1% H_2SO_4		
1%	0·5%	0·1%	1%	0·5%	0·1%
*	··++	··++	·+++	···+	··++

Key: + = definite greening.
d = damage.
· = no response.
* = the insulating tape which was very old did not adhere in this set.

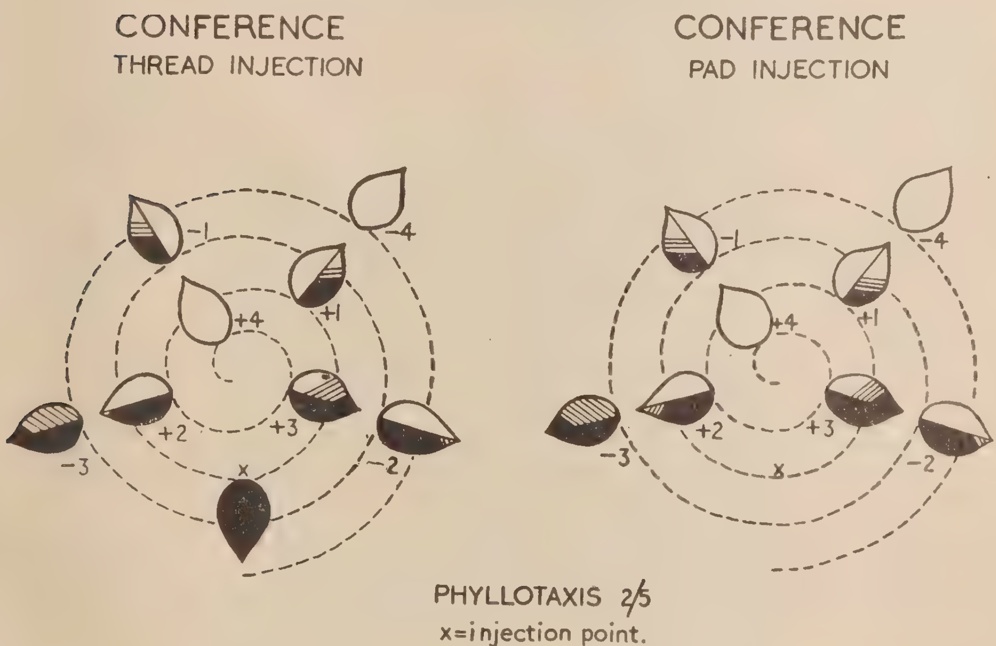

FIG. 3.

Comparative results of injection, by the thread and pad methods, of chlorotic leafy shoots of pear.

Another exploratory experiment with the pad method was carried out on a chlorotic Conference pear, thought, from the symptoms shown, to be iron deficient. In spite of a start made rather late (early August) for responses to be expected, strong responses became evident in five days. The results were as follows :—

Ferrous sulphate + $0 \cdot 1\%$ H_2SO_4.

10%	5%	1%	0·5%
d d d d	d d d d	+ + + +	+ + + +

There was little difference between the responses to 1 per cent. and $0 \cdot 5$ per cent. solutions, though the former appeared to be slightly better than the latter.

The experiment was then repeated using $FeSO_4$ and $MnSO_4$ at 1%, $0 \cdot 5\%$ and $0 \cdot 1\%$ concentrations. Each injection was repeated six times. No strong responses were obtained from the injection with $MnSO_4$, but the following were obtained with ferrous sulphate :—

	$FeSO_4$ + $0 \cdot 1\%$ H_2SO_4	$MnSO_4$ + $0 \cdot 1\%$ H_2SO_4
1% ..	+ + + + + ?	· · · · ? ?
0·5% ..	· + + + + ?	· · · · · ·
0·1% ..	· · · + ? ?	· · · · · ·

Key: + = strong response.
? = response in one leaf observed after 10 days.
· = no response.

Injections done after the middle of August gave no responses. The distributions of the responses to the thread and the pad methods of injection are shown on the phyllotaxis diagram in Fig. 3. It will be seen that they are closely similar to each other and to that resulting from the tube method of injection.

SUMMARY.

Two modifications of the Roach method of diagnostic injection for the detection of nutrient deficiencies in plants, are described.

In the first a short length of soft cotton thread impregnated with the test solution and afterwards dried, is drawn with a fine darning needle through a leaf petiole or other tissue. In the second, a pad of cotton wool moistened with the test solution, is bound with a piece of waterproof surgical or insulating tape over the wound caused by removing a leaf at the base of its petiole.

The distribution of the reagent in the cases tested (apple, pear, quince and Hydrangea) and the consequent development of chlorophyll, was the same as that resulting from the Roach tube method of injection.

The modifications described involve the use of easily obtained materials ; manipulation is simple and the trials are not adversely affected by wind, wet weather or capillary creeping of the solution over hairy surfaces.

ACKNOWLEDGMENTS.

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PLATE I.

FIG. 1.

Chlorotic leafy shoot of Hydrangea showing response to injection with $FeSO_4$, by the pad method, at the base of the petiole of the leaf situated below that marked X.

FIG. 2.

A chlorotic leafy shoot of quince which was injected with $FeSO_4$ by the thread method, through the petiole of the leaf X. The dark areas show where the green colour developed in this leaf and in the others above and below it.

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DISTRIBUTION OF TEMPERATURES IN POTATO CLAMPS AND THEIR INFLUENCE ON SPROUTING AND SUGAR CONTENT

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Because of the lack of published information on the temperatures that occur in potato clamps in this country* an investigation was carried out about ten years ago at the Kirton Agricultural Institute in South Lincolnshire, during which the temperatures in different parts of a clamp were recorded throughout the winter. The influence of variations in temperature on the incidence of sprouting and on the sugar content of the potatoes was determined when the clamp was finally opened.

Methods of measuring temperatures.

Distant-reading thermometers suitable for recording the temperatures in different parts of a clamp were not available and the method adopted was that commonly used in ships' refrigerated spaces namely, wooden thermometer tubes, built into the clamp during its construction, in which lagged mercury thermometers could be permanently suspended.

The thermometer tubes were 4 and 6 feet in length and were made of two channel-section halves screwed together to give a round bore about 0·8 in. diameter in a cross-section of 1·8 in. square. The lower ends were perforated with three circular holes, ½ in. diameter, to facilitate equilibration of temperature.

The thermometers were hung in the tubes on lengths of silk with the bulbs (lagged with plasticine) opposite the holes just mentioned ; the ends of the threads were knotted into corks closing the upper ends of the tubes, and the tubes projected some 6 in. from the side of the clamp. To avoid the possibility of introducing vertical air-channels, which would alter the normal temperature conditions, the tubes were installed at an angle of about 50 degrees from the vertical. With this angle it was necessary to propel the thermometers down the tubes with some force, since the lagged bulbs would not slide easily.

To diminish the risk of the thermometer readings being influenced by the temperature of the air around the upper end of the thermometer tube, a wad of cotton wool was fitted below the cork. The top of each tube was covered with an inverted flower pot for protection from rain.

Experiment 1 (1934-35).

In the autumn of 1934 a clamp of King Edward potatoes, about 50 ft. long and 3½ ft. high, orientated approximately east and west, was divided into three sections by vertical wooden frames placed at right angles to the long axis. In each section four thermometer tubes were arranged to record the temperatures in the positions top (T), bottom (B), south (S), north (N), shown in Fig. 1. Comparable samples—each of about 100 tubers of the same variety, enclosed in a net bag—were located near each thermometer. At the end of the period the effect of temperature differences on sprouting and sugar content was determined on these samples. The three sections were treated as follows :—

* Continuous records of the temperatures at various points in a number of potato clamps were made in 1943 and 1944 by E. M. Crook and D. J. Watson, of Rothamsted Experimental Station ; the results are to be published shortly.

(1) *Ordinary.* The initial covering of straw and earth was supplemented by the winter coat on November 27th, giving a final covering of 8 in. of earth at the sides and 4 in. of earth at the top, the latter decreasing during the winter to 1 in. through washing by rain.

(2) *Shaded.* Covering of straw and earth as above; in addition, a sloping wooden frame was constructed on the south side to shield the clamp from the sun; the frame was parallel to the side of clamp and separated from it by a distance of about 20 in.; the top of the frame was level with the ridge of the clamp.

(3) *Double-earthed.* In addition to the coverings of straw and earth as above, an extra covering of earth was added, giving a final covering of 14 in. of earth at the sides and 8 in. on the ridge.

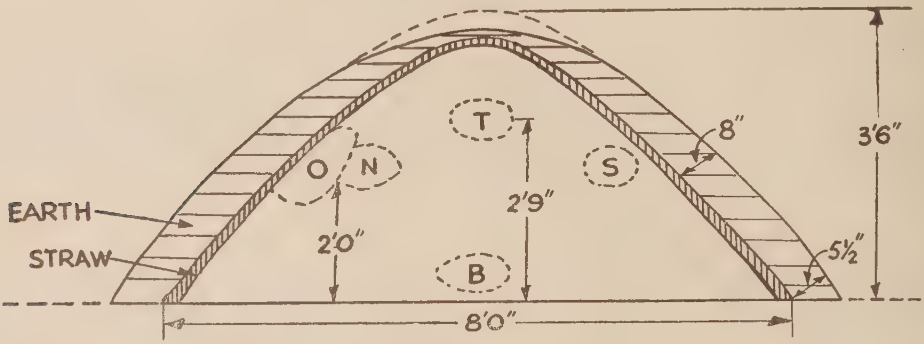

FIG. 1.

Cross-section of clamp showing its dimensions and the positions in which experimental samples were stored and temperatures measured.

Temperatures.

It soon became apparent that even in the more exposed positions in the sections the temperatures in the thermometer tubes only slowly followed the changes in the outside air temperature. It was accordingly decided to record temperatures at intervals of about 3-5 days, in the morning whenever possible. Except when the weather was rapidly becoming colder, evening readings would probably have been rather higher throughout.

The mean readings of the four thermometers in the ordinary and the double-earthed sections are plotted in Fig. 2A and, for comparison, screen temperatures (for alternate days), obtained from a weather station about one mile from the clamp, have been added. These air temperatures are the means of the daily extremes recorded by maximum and minimum thermometers; they afford a sufficiently accurate index of the mean daily temperature for the present purpose.

The mean temperature in the double-earthed section was influenced only by the main trends in the outside air temperature—i.e. a slow rise to mid-December, followed by a prolonged fall (Fig. 2A). The mean temperatures in the ordinary and the shaded* sections were more variable than those in the double-earthed section, and the variations were more closely correlated with those in the outside air temperatures, though considerably reduced in magnitude.

The relation of the temperatures in the three sections and of the air temperatures are shown, amongst other things, in Table I, which gives the mean temperatures throughout the four months period November 3rd, 1934 to March 4th, 1935.

Sprouting and Sugar-content.

Table I also gives average figures for each section for the sprouting and sugar-content of the samples stored in the nets previously mentioned. The sprouting was recorded as a

* Records omitted from Fig. 2A for clarity; the values were close to those for the ordinary section.

percentage weight of sprouts removed from a given weight of potatoes, when the clamps were opened on March 4th, 1935. Samples for sugar analysis were frozen on March 7th, 1935.

TABLE I.

Average temperatures, sprouting and sugar-content in ordinary, shaded and double-earthed sections, 1934-35. (Figures are means of the separate values for the four positions.)

	Air.	Ordinary.	Shaded.	Double-earthed.	Cold storage.
Temperature °F.	42·0	45·0	46·0	50·0	41·0
Sprouting (%)	—	0·48	0·80	0·97	0·0
Total sugar (%)	—	0·69	0·53	0·46	0·96

From Table I it will be seen that the average temperature in the double-earthed section was roughly 5° F. above that of the ordinary one and, corresponding with this, the sprouting in the double-earthed section was twice that in the ordinary one; in contrast, the sugar content was lower in the double-earthed than in the ordinary section, a result which was anticipated since it is well-known that the lower the temperature the greater the tendency for the production of sugar.

A comparable sample of potatoes stored throughout the above period in a constant temperature room at 41° F. showed no sprouting but higher sugar-content than in any of the sections, as recorded in the last column of Table I.

EXPERIMENT 2 (1935-36).

In the autumn of 1935 a second experiment was made on similar lines, but omitting the shaded section, and adding a fifth position for a thermometer tube, namely, an outside one, as at O in Fig. 1.

The King Edward potatoes were smaller than in 1934-5 and the clamp was thus flatter than in Fig. 1. The ordinary section was on November 6th covered with $1\frac{1}{2}$ in. of straw and $4\frac{1}{2}$ in. of earth on the south side, 3-6 in. of straw and $4\frac{1}{2}$ in. of earth on the north side and 1 in. of straw on the ridge. On December 6th, earth was added to give the winter coat, the final coverings being 5-8 in. of earth on the south side, 5-6 in. on the north side, and 4 in. on the top; the last named decreased during the winter to 1 in. through washing by rain.

In the double-earthed section the final coverings were 1-3 in. of straw (packed more tightly than in the ordinary section owing to the greater weight of earth) at the sides and top, with 14 in. of earth on the sides and 8 in. of earth at the top.

To check the accuracy of the thermometer tube method of measuring temperatures, a mercury-in-steel distant-reading thermometer was inserted at the bottom of the double-earthed section. The average readings of this thermometer were approximately 0·5° F. above those in the four thermometer tubes, showing that the readings of the latter were reasonably accurate.

Temperatures, Sprouting and Sugar-content.

The mean readings of the four thermometers in each section and the outside air temperatures for alternate days for the four-month period November 8th, 1935 to February 27th, 1936 are plotted in Fig. 2B. The readings for position O are omitted to make the figure comparable with Fig. 2A.

Comparison of Fig. 2A and B shows that the drifts of temperature, both air and clamp, differed markedly in the two seasons. In 1935-6 there was a prolonged period of low temperature in December as well as rather lower temperatures after Christmas than in 1934-35.

The relation of the temperatures in the two seasons is readily seen by comparing Table II for 1935-36, with Table I for 1934-35. The sprouting was recorded on February 27th, 1936 when the samples for sugar analysis were removed; the latter were frozen for analysis on March 2nd, 1936.

TABLE II.

Average temperatures, sprouting and sugar-content in ordinary and double-earthed sections, 1935-36. (Figures are means of the separate values for the four positions.)

	Air.	Ordinary.	Double-earthed.
Temperature °F.	37·5	43·0	44·5
Sprouting (%)	—	0·16	0·21
Total sugar (%)	—	0·70	0·54

Although the mean air temperature in 1935-36 was 4·5° F. lower than in 1934-35 the mean temperature in the ordinary section was only 2° F. lower than in the previous year. The

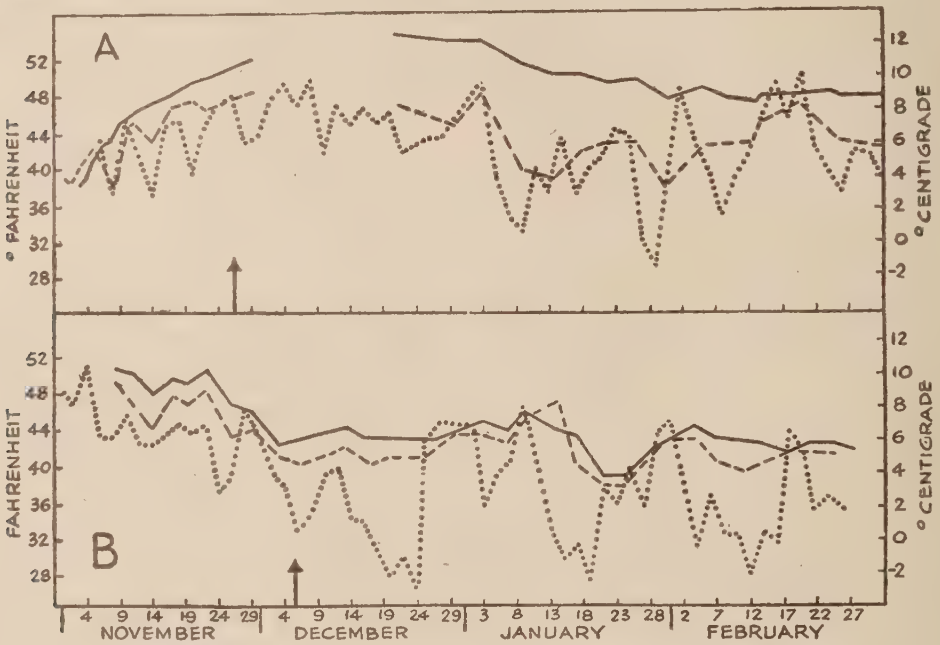

FIG. 2.

Temperature (Mean values for the four positions) in ordinary and double-earthed clamps and screen temperatures at weather station.

A 1934–35. – – – – Ordinary.
B 1935–36. ——— Double-earthed.
· · · · Screen.

Vertical arrow indicates addition of extra earth to clamp.
The temperatures were not recorded in the sections during the period from November 29th to December 21st, 1934.

difference in temperature between the ordinary and the double-earthed sections was much less in 1935-36 than in 1934-35; and, corresponding with the smaller difference in temperature between the sections in 1935-36, the differences in sprouting and sugar-content were smaller. As in 1934-35, sprouting was lower and the sugar-content higher in the ordinary section than in the double-earthed one.

The above temperature differences in the two seasons would be accounted for if the ordinary section was more heavily covered with soil and the double-earthed one less well-covered

in 1935-36 than in 1934-35. The thicknesses of the straw and earth coverings were not, however, markedly different in the two seasons, but in 1935-36 the potatoes were muddy when clamped, as compared with their dry, clean condition in 1934-35. Since the introduction of earth among the potatoes would restrict air-movement, this difference may be responsible for the relatively higher temperature of the ordinary section in 1935-36; the small difference in temperature between the ordinary and double-earthed sections in 1935-36 remains, however, unexplained.

VARIATION IN TEMPERATURE, SUGAR-CONTENT AND SPROUTING.

The variation of temperature between different positions within the sections, particularly in the ordinary one, may be larger than the difference between the average values for ordinary and double-earthed sections. Fig. 3 shows the readings for the two positions of extreme

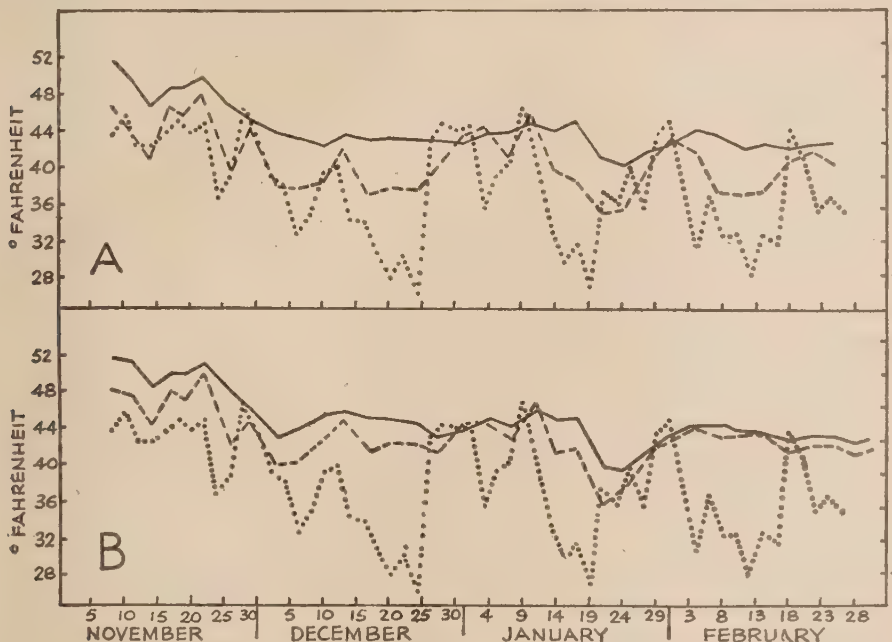

FIG. 3.

Temperatures in the two positions of extreme temperature: in A, ordinary clamp; B, double-earthed clamp, 1935–36.

Screen temperatures from weather station also shown.

——— Bottom.
– – – – South.
· · · · Screen.

temperature in the ordinary and double-earthed sections in 1935-36; the full data for the four positions in the ordinary and double-earthed sections in 1935-36 and 1934-35 are summarized in Table III.

In the ordinary section (1935-36), Table III (*a*), there was a range of temperature of 4° F and this was associated with a wide difference in the sugar-content and sprouting. The close correlation between the fall of temperature from the bottom to the south positions, the decrease in sprouting and the inverse trend of sugar-content, are noteworthy.

Except for the outside position, the double-earthed section (1935-6) (Table III (*b*)) showed much less variation, both in the temperatures, the sugar-content and the amount of sprouting, than the ordinary section. The temperatures recorded in the double-earthed section in 1934-5 were higher, and the sprouting and sugar-content in the different positions were more uniform than in the double-earthed section of 1935-36 (Table III (*d*)).

TABLE III.

Average temperature, sprouting and sugar-content in different positions in ordinary and double-earthed sections in 1935-36 and 1934-35.

Position in Section :—	Bottom.	North.	Top.	South.	Surface.
(*a*) *Ordinary* (1935-36) :					
Average temperature °F. ..	44·5	44·5	41·5	40·5	43·0
Sprouting (%)	0·26	0·20	0·12	0·08	0·24
Total sugar (%)	0·51	0·62	0·80	0·85	0·92
(*b*) *Double-earthed* (1935-36) :					
Average temperature °F. ..	45·0	45·5	45·0	43·5	40·5
Sprouting (%)	0·31	0·19	0·21	0·13	0·16
Total sugar (%)	0·40	0·56	0·53	0·67	0·87
(*c*) *Ordinary* (1934-35) :					
Average temperature °F. ..	45·5	45·5	43·0	45·5	—
Sprouting (%)	0·41	0·46	0·37	0·67	—
Total sugar (%)	0·44	0·98	0·78	0·56	—
(*d*) *Double-earthed* (1934-35) :					
Average temperature °F. ..	51·0	50·0	49·0	48·5	—
Sprouting (%)	0·93	1·20	0·77	0·97	—
Total sugar (%)	0·42	0·46	0·46	0·51	—

DISCUSSION.

The data presented show that the mean temperature in the sections was, in general, higher than the mean temperature of the surrounding air by a few degrees Fahrenheit. The difference between the mean temperatures for section and air was increased by adding to the thickness of the coverings of earth and straw. In addition to conserving the heat produced by the potatoes, however, the coverings also exerted a marked insulating effect, which was greater the thicker the covering ; the sectional temperatures thus responded only slowly to changes in the surrounding air-temperatures.

There were surprisingly large variations in temperature from point to point in the ordinary sections. Thus, during the cold spells in 1935-36 (Fig. 3) the temperature in the south position was 7-8° F. below that in the bottom position, and the mean difference between these two positions throughout the period of the observations was 4° F. (Table III (*a*)).* This difference in temperature was associated with a difference in sprouting of from 0·26 per cent. to 0·08 per cent., and in sugar-content of from 0·51 per cent. to 0·85 per cent.

The variation of temperatures, sprouting and sugar-content within the sections was markedly reduced by increasing the thickness of the covering layers (Table III (*b*)), but the extra covering naturally increased the general temperature. Thus, the mean temperature in the double-earthed section in 1934-35 was 6° F. above that in the ordinary one, and the higher temperature was correlated with a doubling of the extent of sprouting. On the other hand, the mean sugar-content was reduced from 0·69 per cent. to 0·46 per cent. (Table I).

The data for different positions in the sections show that both the sprouting and sugar-content were affected by the temperature, the sprouting being greater and the sugar-content lower the higher the temperature (Table III). The outside position in both the ordinary and the double-earthed sections in 1935-36 was, however, exceptional in showing high or medium sprouting with high sugar. Moreover, general observations indicated that the sprouting was more vigorous in the outside 2-3 in. layer of potatoes along the ridge than elsewhere in the sections. Since this outer zone along the ridge must, like the outside position selected, have been at a lower average temperature than the bottom of the clamp, it would appear that the

* The lowest temperature noted in the sections was 35° F. (Fig. 3A). Examination of the weather records at Kirton for the years 1930 to 1940 showed that the winter was much milder than the average in December, 1934, and appreciably milder than the average in January and February, 1935. The winter of 1935-36 was colder than the average in December, January and February.

greater incidence of sprouting in these two zones must have been related to the influence of a factor other than temperature.

In earlier work (1) sprouting was found to be markedly greater on the south than on the north side of a potato clamp, and this difference was attributed to the direct heating of the south side by the sun. In the present experiment, however, shading the clamp on the south side (Experiment 1) did not reduce the temperature on this side, but increased it (presumably by restricting the movement of air over or through the clamp coverings), so that the mean temperature was higher in the shaded than in the ordinary clamp (Table I). Moreover, in 1935-36 (Experiment 2) the south position was lower in temperature and showed markedly less sprouting than the north (Table III (*a*)).

These observations suggest that the direct effect of the sun on the temperature in the clamp is small (at least until the beginning of March), and that whether the north or south side is the colder will depend on other factors, e.g. the relative thickness of the coverings on the two sides and the direction of the wind.

There is no doubt that the potatoes at the extreme outside of the clamp would be lower in temperature than those in the respective north, south and top positions selected, which were roughly one foot from the surface (Fig. 1). For this reason a sample was placed in an outside north position in Experiment 2 (Fig. 1, position O). Although the temperature recorded for this position was higher than can reasonably be accepted as correct, the sugar-content was appreciably greater than in the corresponding north position (Table III). A still higher sugar-content might have been expected in an outside south position. In each of the five sections tested, the bottom position was higher in temperature and lower in sugar-content than the other positions.

It is common knowledge that occasionally during the winter, and particularly after spells of severe cold, potatoes bought for domestic purposes are of sweet flavour and inferior cooking quality. How much of this damage has occurred while the potatoes were in the clamps and how much has been caused during distribution and marketing have been open questions. The results discussed above suggest that some damage must occur in the clamps.

In this investigation no tests were made of the culinary quality of the various samples. From subsequent work, however, (2) it seems probable that in both seasons, the bulk of the potatoes from the double-earthed sections would have made excellent potato crisps. On the other hand, a large proportion of the tubers in the ordinary section, and especially the samples from the colder parts, would probably have yielded crisps of poor quality owing to their unduly high sugar-content. Further experiments are needed to confirm this deduction and to show whether the culinary quality of the tubers when cooked by other methods, e.g. by boiling or by frying as chips—methods in which the quality is less influenced by small increases of sugar than is the manufacture of crisps—is affected by the temperatures in the clamp.

In the present experiments no determinations of the carbon dioxide content of the atmosphere of the clamps were made, since earlier unpublished work had shown that the percentage of this gas in a clamp of normal construction lay between 0·1 and 0·3 per cent.* This observation suggested that, in general, an appreciable accumulation of carbon dioxide would be unlikely to occur; an influence of carbon dioxide on culinary quality would then not be anticipated.

SUMMARY.

The records of the temperatures at four positions in a sectioned potato clamp of normal construction during two successive winters showed that the mean temperature in the clamp was a few degrees Fahrenheit above the mean temperature of the surrounding air. The clamp coverings had an insulating effect, the variations in the temperatures of the clamp being much smaller than those in the air temperatures. Adding to the thickness of the clamp coverings not only increased the difference between the mean temperature in the clamp and that of the surrounding air but also reduced the variations in temperature within the clamp.

There were marked differences in temperature between various positions in the clamp,

* These values are similar to those found by Smith (3) during the bin storage of potatoes.

and these variations were found, in general, to be correlated with differences in the extent of sprouting and content of total sugar determined when the sections were opened. The variations were diminished by increasing the thickness of the coverings.

ACKNOWLEDGMENTS.

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THE STORAGE AND RIPENING OF GREEN TOMATOES, WITH SPECIAL REFERENCE TO OPEN-AIR FRUIT AND END-OF-SEASON FRUIT FROM GLASSHOUSES

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Introduction.

Before 1940 the growing of tomatoes in the open-air was practised on only a comparatively small scale in this country and the amount of fruit which failed to ripen on the plants owing to the onset of cool weather was negligible from a commercial standpoint. In the glasshouse industry there are often fairly large quantities of green fruit left at the end of the season when it is no longer economical to continue the heating of the houses. In general this fruit is stripped from the plants and either sold directly for pickle manufacture or allowed to ripen in a vacant house or shed along the lines recommended by Bewley (2). The ripening of green fruit has tended, however, to be of secondary importance in the past because imported ripe fruit was available in the late autumn and winter at a low price.

The situation is now somewhat different ; there has been a considerable increase in the quantity of tomatoes grown in the open air and, although some decline in this activity may occur, it seems certain that the production of open-air fruit will remain at a much higher level than it was before 1940. Much greater quantities of green fruit are, therefore, likely to be left for disposal than formerly, and the fullest utilization of the produce has become a matter of importance in view of the fact that imports of tomatoes are likely to be limited for some years to come.

The greater part of any supply of green fruit as it normally occurs, either from open-air or glasshouse sources, can be ripened satisfactorily and a supply of tomatoes assured over a period of several weeks after the final harvesting if Bewley's recommendations are followed.

As a result of the increased interest in the value of this green fruit, however, a number of questions have been raised as to the possibilities of controlling the ripening more effectively so that, on the one hand, supplies can be ripened more quickly and evenly and, on the other hand, ripening can be retarded in order to prolong the period of supply further.

With these questions in mind experiments were carried out in 1945 with green fruit from both open-air and glasshouse sources to determine : (*a*) the maximum period of keeping between picking and marketing when using a low temperature for storage followed by a higher one for ripening, (*b*) the effect of storage in artificial atmospheres, (*c*) the effect of allowing the fruit to remain on the stem during storage and ripening, and (*d*) the effect of treatment with ethylene.

The following report gives details of the results of these experiments and also includes observations on the ripening of tomatoes from experimental plots which had received different manurial treatments. The latter are of interest in showing that the rate of ripening is influenced by the cultural treatments.

Details of the experiments.

The fruit used was of the variety Harbinger, picked on September 3rd and October 12th from the same group of plants grown in the open air at Stone Hill Green, near Swanley, Kent, and of the variety Market King, picked on October 31st, from plants grown under glass at New Barn Nursery, also near Swanley.

The fruit selected was fully grown but still green ; it was picked in the morning and taken immediately to the laboratory for division into the requisite number of samples of 25 fruits each. All samples were placed on paper lined trays and put into the store or the ripening room during the afternoon. In all the experiments storage and ripening were carried out in the dark ; the humidity of the air was not controlled. The fruit of the first gathering of Harbinger

was large and somewhat coarse, and mechanical damage from wind or cracking was in evidence, whereas that of the second gathering was a little smaller and was in better condition. The Market King fruit from under glass was small, but free from injuries or blemishes.

Samples were stored in air at 40°, 45°, 50°, 55° and 65° F. and at intervals withdrawn from the lower temperatures and transferred to 65° F. to ripen. The glasshouse fruit and the late gathered open-air fruit was ripened at 65° F. both in ordinary air and in air containing 0·1 per cent. of ethylene. For the latter purpose the samples were placed in a cabinet of about 15 cu. ft. capacity through which air containing 0·1 per cent. ethylene was passed at a rate of about 10 litres per hour.

Storage in artificial atmospheres was carried out with the Market King tomatoes at 55° F., using the two mixtures 5% O_2+5% CO_2+90% N_2 and 5% O_2+10% CO_2+85% N_2, and also at 50° F., using 5% O_2+10% CO_2+85% N_2. These particular mixtures were the most effective amongst those previously tried on tomatoes by Kidd and West (3) although not necessarily the best.

For observations on the ripening of fruit left on the truss, selected trusses with 6 in. to 9 in. of the main stem attached were cut from a number of the Harbinger open-air plants at the time of the second gathering on October 12th. Any very small immature fruits were detached and the trusses were divided into samples each consisting of 3 or 4 trusses providing a total of 25 to 30 fruits. Samples were kept at 65°, 55° and 50° F. throughout, and transfers were also made periodically from 55° and 50° F. to 65° F. for ripening.

A comparison was made of the ripening at 60° and 65° F. of samples of the first gathered Harbinger fruits. Ripening was equally satisfactory at both temperatures and of course more rapid at 65° F. For this reason 65° F. was adopted as the standard ripening temperature.

The observations on the effect of manurial treatments on ripening were made on samples of fully grown, green fruits of Harbinger picked from the experimental open-air plots at the Kent Education Committee's Glasshouse Demonstration Station, Swanley.

The plots (which were properly randomized) had received the following manurial treatments before planting : no treatment, nitrogen only, potash only, nitrogen + potash, nitrogen + potash + phosphate. Fifty fruits were picked on October 10th, 1945, just before the final gathering of the season, from plants from the randomized plots of each of the five treatments. The fruit from all the treatments showed little difference in appearance. It was green and small to medium in size, but just at the beginning of the turning stage. The samples were placed on trays to ripen at 65° F. within two hours from the time of picking.

Behaviour during continuous storage at 40°, 45°, 50°, 55° and 65° F.

Samples were kept continuously at all the temperatures and the observations made on the progress of ripening were as follows :

(1) *Harbinger, gathered September 3rd* (Table I).

65° F.—Ripening proceeded steadily and the whole of the sample had ripened by the 29th day. Many of the fruits had a blotchy appearance during the intermediate stages, but all eventually developed a good red colour. Wastage due to rotting exceeded 20 per cent. by the time the whole of the sample had ripened, but the rotting was confined to those fruits which were becoming over-ripe.

55° F.—Only 56 per cent. had reached the ripe stage on the 38th day and extrapolation of the ripening curve indicated that the time for complete ripening would have been about 60 days. On the 38th day wastage due to rotting was 32 per cent. As in the sample ripened at 65° F. the wastage was confined to fruit that had ripened, but it developed soon after the fruit had coloured. Thus the life of ripe fruit from 55° F. tended to be less than that from 65° F. The colour developed was good and similar to that at 65° F.

50° F.—Ripening was exceedingly slow at this temperature. Only 8 per cent. had ripened by the 38th day, when more than 30 per cent. of the fruit had rotted. The colour of the ripe fruit was pale.

45° F.—Only 40 per cent. had " turned " and none had reddened by the 38th day, when 40 per cent. of wastage had developed.

40° F.—Very little change of colour took place in 28 days by which time all the fruits had numerous small rotted areas scattered over the surface. This rotting was typical of that which develops as the result of severe low temperature injury.

TABLE I.

The behaviour of green Harbinger tomatoes, picked on September 3rd and stored at various temperatures.

Temperature of storage, °F.	Days to complete ripening.	Percentage rotting at complete ripening.	Remarks.
65	29	22	Good colour, only ripe fruit rotted.
55	*circ.* 60	32 on the 38th day.	,, ,, ,,
50	Only 8% on 38th day.	30 ,, ,,	Ripe fruit of poor colour.
45	Failed to colour.	40 ,, ,,	
40	,, ,,	100 on the 30th day.	

(2) *Harbinger, gathered October 12th* (Table II).

65° F.—The whole of the sample had ripened by the 24th day with the development of a good colour, and only 4 per cent. of rot had developed. The general appearance was somewhat better than that of the early fruit.

55° F.—75 per cent. of the sample had ripened by the 34th day and the whole of the sample by the 40th day. 30 per cent. of rot was present on the 34th day, but this was confined to the ripe fruit.

50° F.—Only 8 per cent. had ripened by the 34th day when 30 per cent. of rot was present.

45° F.—None had reddened and only 40 per cent. of the fruits had "turned" by the 38th day when 40 per cent. of rot was present.

40° F.—Little colour change had occurred by the 38th day when general rotting developed similar to that in the early fruit at this temperature.

TABLE II.

The behaviour of green Harbinger tomatoes, picked on October 12th and stored at various temperatures.

Temperature of storage °F.	Days to complete ripening.	Percentage rotting at complete ripening.	Remarks.
65	24	4	Good colour, better appearance than early fruit.
55	40	30 on the 34th day.	Good colour, rotting of ripe fruit only.
50	Only 8% on 34th day.	,, ,,	
45	Failed to colour.	40 on the 38th day.	
40	,, ,,	100 on the 35th day.	

(3) *Market King, late, glasshouse grown* (Table III).

65° F.—85 per cent. of the sample had ripened by the 20th day, the remaining 15 per cent. had completed their ripening by the 29th day. The appearance and colour were very good and the sample was without rot at this stage.

55° F.—90 per cent. of the sample had ripened by the 33rd day with less than 10 per cent. of rot, which was confined to the ripe fruit. The remaining 10 per cent. completed their ripening by the 46th day when rot had increased to nearly 30 per cent. as a result of over-ripeness.

50° F.—50 per cent. of the sample had ripened by the 33rd day when rot was less than 10 per cent. and was confined to the ripe fruit. Rot developed fairly rapidly after the 33rd day and 24 per cent. was present on the 43rd day (some partially ripe fruits being affected) when only about 50 per cent. had ripened. The time, by extrapolation, for the whole of the sample to ripen was about 65 days.

45° F.—Ripening proceeded slowly ; by the 43rd day 12 per cent. of the fruits had ripened with development of a somewhat pale colour, but rot exceeded 20 per cent. and partially ripe fruit was largely affected.

40° F.—The fruit failed to colour but some change to a yellow green was apparent by the 37th day when rot exceeded 40 per cent. All the rotting developed at the stem-end of the fruit and the difference in the type of rot as between this and the open-air fruit was quite marked.

TABLE III.

The behaviour of green Market King tomatoes picked on October 31st from under glass and stored at various temperatures.

Temperature of storage °F.	Days to complete ripening.	Percentage rotting at complete ripening.	Remarks.
65	29	Nil.	Excellent appearance.
55	46	28	Rotting only in ripe fruit.
50	56% ripe on 43rd day.	24 on the 43rd day.	Rotting mainly in ripe fruit.
45	12% ,, ,,	28 ,, ,,	Poor colour.
40	Failed to colour by 37th day.	44 (stem-end) on 37th day.	

The observations indicate that there was no marked difference between early and late gathered open-air fruit harvested in the green state with regard to its behaviour at various temperatures. The fruit coloured very slowly at 50° F. and at temperatures lower than this the normal red colour failed to develop. The development of severe wastage from rotting before ripeness indicated that the resistance to infection was seriously weakened eventually at all temperatures below a point between 55° and 50° F.

The fruit grown under glass appeared to be able to tolerate a lower temperature than that grown in the open air. Ripening proceeded normally at 50° F. and the fruit coloured slowly even at 45° F. Serious wastage before ripeness did not occur at temperatures above about 45° F. It is not possible to say to what extent this difference may be varietal.

By storing open-air fruit at 55° F. it was thus possible to procure a supply of ripe fruit over a period of about 60 days for the first pick and 40 days for the second. At 65° F. these periods were approximately halved.

With glasshouse tomatoes a supply of ripe fruit was obtained over a period of about 65 days by storing at 50° F., without serious risk of heavy wastage from rotting, over about 46 days by storing at 55° F., and over 29 days by storing at 65° F. In general there was a tendency for the fruit to be paler and less attractive in colour the lower the ripening temperature, but this tendency was not very pronounced in the glasshouse fruit.

RIPENING AT 65° F. IN AIR AFTER DIFFERENT PERIODS OF STORAGE AT 50°, 45° AND 40° F.

In order to determine the maximum time that the green fruit could be stored without adversely affecting its subsequent ripening at 65° F. in air, samples were stored at lower temperatures which inhibited or markedly retarded ripening, namely 40°, 45° and 50° F., and were periodically transferred to 65° F. for observations on ripening.

(1) *Harbinger, gathered September 3rd* (Table IV).

40° F.—The samples stored for 5, 7 and 9 days at 40° F. ripened subsequently at 65° F. in approximately the same time as the fruit kept at 65° F., from the time of picking (Table I). Increasing the period of storage to 12 days resulted in appreciably slower ripening. The effect of storage on the susceptibility to rotting was pronounced ; up to 7 days at 40° F. the resistance to rotting appeared to be very little affected, but after longer periods the rate of rotting at 65° F. was much more rapid. Thus, in the samples stored for 5 and 7 days, rotting to the extent of 20 per cent. did not develop until the 25th and 22nd days, respectively, at 65° F. and it was confined to fruit that had ripened. In the samples stored for more than 7 days the rotting

TABLE IV.

The behaviour of early gathered Harbinger tomatoes at 65° F. after storage for different periods at 40°, 45° and 50° F.

Temperature of storage °F.	Days in store.	Days at 65° F. to complete ripening.	Days at 65° F. to 20% rotting.	Remarks.
40	5	27	25	Rotting of ripe fruit.
	7	31	22	,, ,,
	9	32	13	Rotting of unripe fruit.
	12	40	13	,, ,,
45	7	25	25	Rotting of ripe fruit.
	12	32	26	,, ,,
	17	31	15	Rotting of unripe fruit.
	22	40 (*circ.*)	8	,, ,,
50	7	22	22	Rotting of ripe fruit.
	12	27	17	,, ,,
	19	25	10	,, ,,
	26	19	9	,, ,,
	33	—	3	Rotting of unripe fruit.

which developed at 65° F. reached 20 per cent. in only 13 days, both ripe and turning fruit being affected.

45° F.—Storage at 45° F. for a period up to about 17 days did not appear to affect the rate of ripening at 65° F., beyond this period the fruit was affected and its rate of ripening at 65° F. was slower. Resistance to rotting was seriously affected after about 14 days. Thus, rotting did not reach 20 per cent. until after the 25th day at 65° F. in the samples previously stored for 7 and 12 days. In the sample stored for 17 days, however, this level of rotting was reached on the 15th day at 65° F. and partially ripe fruit was also involved.

50° F.—Storage at 50° F. for 33 days did not affect subsequent ripening at 65° F.; the time taken for ripening following storage decreased with increasing length of the storage period, since at 50° F. ripening was proceeding slowly and was accelerated in a normal manner when the temperature was raised. Resistance to rotting appeared to be affected after about 21 days; in the samples stored for 26 days or more, rotting developed subsequently at 65° F. before the fruit had fully ripened.

In contrast with the samples stored at 40° F. and 45° F., there was a pronounced tendency for rotting to develop earlier at 65° F. the longer the storage period, even before storage had been sufficiently prolonged to lower resistance to the point at which invasion of unripe tissue was possible. The explanation of this may lie in the fact that at 50° F. spore germination and mould growth is considerably more active than at 45° or 40° F., so that on transfer to 65° F. the rot-producing organisms were able to develop actively without delay wherever favourable conditions (e.g. cracks in the skin) occurred.

(2) *Harbinger, gathered October 12th* (Table V).

The general behaviour in relation to temperature was similar to that of the early gathered fruit.

40° F.—The fruit stored for 5 days at this temperature subsequently ripened satisfactorily at 65° F. over a period of 23 days with the development of only slight rot. Storage for 11 days followed by ripening at 65° F. resulted in the development of serious rot by the 13th day, long before the sample had completely ripened.

45° F.—Storage for periods up to 14 days did not seriously affect subsequent ripening at 65° F. The fruit developed good quality, while rotting was confined to ripe fruit and did not assume serious proportions until after the whole of the samples had ripened. Storage for 21 days, on the other hand, led to an early development of rot Unripe fruits were affected and serious rot was present on the 13th day, long before the whole of the sample was ripe.

TABLE V.

The behaviour of late gathered Harbinger tomatoes at 65° F. after storage for different periods at 40°, 45° and 50° F.

Temperature of storage °F.	Days in store.	Days at 65° F. to complete ripening.	Days at 65° F. to 20% rotting.	Remarks.
40	5	23	23	Only 4% ripe fruit rotted on 23rd day.
	11	24	13	Rotting of unripe fruit.
45	7	28	25	Rotting of ripe fruit.
	14	21	21	,, ,,
	21	23	13	Rotting of unripe fruit.
50	7	23	23	Rotting of unripe fruit.
	14	21	18	,, ,,
	21	17	17	,, ,,
	28	—	2	,, ,,

50° F.—Storage for periods up to 21 days at 50° F. did not appreciably affect the ripening at 65° F. The fruit stored for 7, 14 and 21 days ripened normally in 17, 21 and 23 days respectively, and rot, which developed only in ripe fruit, was less than 20 per cent. at the time of complete ripeness. Storage beyond about 21 days led to severe rot; partially ripe fruit was affected at the time of transfer and serious rot had developed by the time the whole of the sample was ripe.

In general the colour of the fruit from both gatherings tended to be paler the longer the period between the beginning of storage and completion of ripening.

(3) *Market King, late, glasshouse grown* (Table VI).

The samples of glasshouse grown fruit were superior to those from the open-air on account of their better colour and freedom from rot. They also differed with regard to the effect of temperature.

TABLE VI.

The behaviour of late gathered Market King tomatoes (glasshouse grown) at 65° F. after storage for different periods at 40°, 45° and 50° F.

Temperature of storage °F.	Days in store.	Days at 65° F. to complete ripening.	Days at 65° F. to 20% rotting.	Remarks.
40	9	33	>33	Less than 10% rot on 24th day.
	12	32	>32	
	16	24	>30	,, ,,
	23	—	7	Rotting of unripe fruit.
45	7	26	>26	Less than 10% on 26th day.
	14	23	>23	Less than 10% on 23rd day.
	22	20	>20	Less than 10% on 20th day.
	28	20	10	Rotting of unripe fruit.
50	7	24	>24	
	14	22	>23	
	22	19	>22	
	28	14	>14	

40° F.—The samples stored for periods of up to 16 days ripened normally, and rot developed only as the fruits became over-ripe. The sample stored for 23 days, however, rapidly developed rot before the fruit ripened.

45° F.—The samples stored for periods of up to 22 days ripened normally and rot developed only as the fruits became over-ripe. Storage for 28 days resulted in injury, rotting developing on partially ripe fruit and serious rot being present before the sample had fully ripened.

50° F.—Storage was carried on up to 28 days and the fruit when subsequently ripened at 65° F. behaved normally and reached maturity without rotting. Serious rot did not develop until a large proportion of the sample had become over-ripe.

THE EFFECT OF GAS STORAGE.

Samples of Market King were stored for 28 days at 55° F. in gas mixtures containing 5% O_2+5% CO_2+90% N_2 and 5% O_2 +10% CO_2+85% N_2 and at 50° F. in the latter mixture. The fruit was then examined and samples from each treatment were ripened at 65° F. in air, in air +0·1 per cent. ethylene, and also at 55° in air with the fruit stored at 55° F.

The condition of the fruits at the end of the four weeks storage period is compared in Table VII with that of comparable fruits stored in air.

TABLE VII.

The condition of Market King tomatoes after storage for 4 weeks in gas mixtures and air at 50° and 65° F.

Treatment.	Development of colour at 55° F. Green %	Colouring %	Red %	Development of colour at 50° F. Green %	Colouring %	Red %
Air	16	16	68	40	36	24
5% O_2 + 5% CO_2 + 90% N_2 ..	69	21	0	—	—	—
5% O_2 + 10% CO_2 + 85% N_2 ..	89	12	0	85	15	0

A marked inhibition of ripening resulted in both gas mixtures. A few fruits from the 5% O_2+10% CO_2+85% N_2 mixture at both temperatures showed a slight whitish-coloured pitting, but apart from this the fruit appeared to be normal.

The fruit from both mixtures at 55° F. ripened with the development of good quality and with negligible rot at both 65° and 55° F. (Table VIII). In appearance and flavour the sample from the 5% O_2+5% CO_2 +90% N_2 mixture was slightly better than that from the other mixture, but both samples compared very favourably with fruit ripened in air throughout at these temperatures. The sample stored at 50° F. ripened at 65° F. with the development of a slight purplish tinge in the red colour, but this was not sufficiently pronounced to detract seriously from the appearance.

TABLE VIII.

The ripening at 65° and 55° F. of samples of Market King tomatoes stored for 28 days in gas mixtures at 55° and 50° F.

Treatment.	Days for complete ripening at 65° F.	55° F.	Percentage rotting at completion of ripening at 65° F.	55° F.
55° F. 5% O_2 + 5% CO_2 ..	13	19	4	4
5% O_2 + 10% CO_2 ..	14	21	4	4
50° F. 5% O_2 + 10% CO_2 ..	19	—	7	—

THE EFFECT OF LEAVING THE FRUIT ON THE STEM DURING RIPENING.

The fruits left on the trusses with a portion of the main stem attached ripened somewhat more slowly than detached fruits kept at the same temperature (Table IX).

The fruits on the stem at 65° F., and at 65° F. following a period at 55° F., took 5 or 6

days longer to ripen than the detached fruit. The samples kept at 50° F. for a period before transfer to 65° F. took from 9 to 13 days longer to ripen.

It is not known whether the appreciably slower rate of ripening of the fruit stored at 50° F.

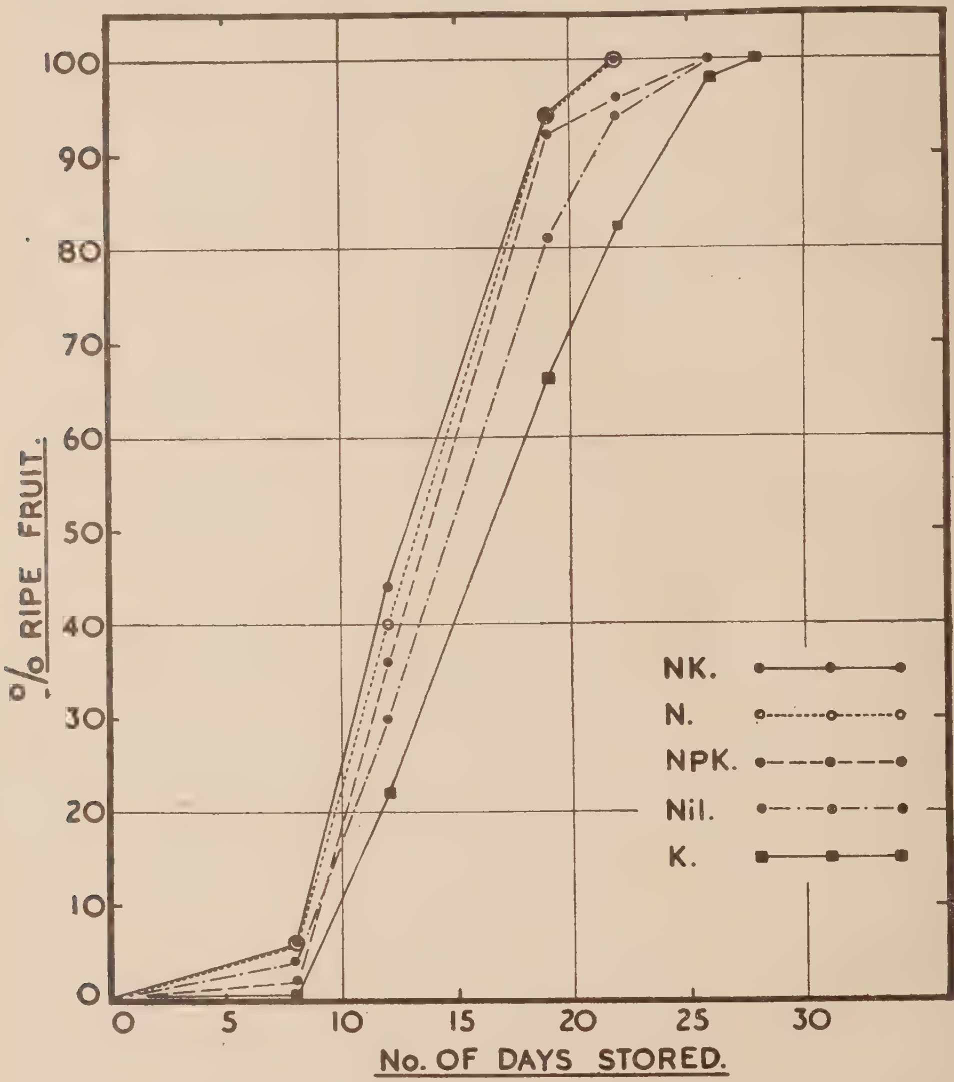

Fig. I. The rate of Ripening at 65°F. of Harbinger tomatoes from plots given different Manurial treatments.

for a time is significant. It is of interest, however, that at 50° F. low temperature injury eventually developed, while at the higher temperature ripening proceeded to completion without injury. A temperature of 50° F. was thus capable in time of producing a profound effect. In view of this it is possible that the slight effect of attachment to the stem shown at the higher temperatures was enhanced by the short exposure to 50° F.

TABLE IX.

The effect of leaving the fruit on the stem on the ripening of tomatoes.

Treatment.	Days to complete ripeness.	
	Fruit on stem.	Detached fruit.
65° F. in air	29	24
50° F. for 8 days, then 65° F. in air.	43	30*
50° F. for 14 days, ,, ,, ...	44	35
55° F. for 8 days, ,, ,, ...	34	28*
55° F. for 14 days, ,, ,, ...	36	31

* These samples were stored for only 7 days at the lower temperature.

The effect of different manurial treatments.

Observations were made on the effect of different manurial treatments on ripening with the Harbinger samples gathered on October 10th from the open-air plots which had received manurial treatments as follows: no treatment, nitrogen, potash, nitrogen + potash, nitrogen + potash + phosphate.

The progress of ripening, as shown by the percentage of fruit which had reached the fully red stage at any given time during the ripening period, is shown in Fig. 1 for each of the five samples.

In the sample from the control plots, which received no treatment, 90 per cent. had ripened by the 21st day and the remaining fruits by the 26th day.

The samples from the plots which had received nitrogen, nitrogen + potash and nitrogen + potash + phosphate, respectively, ripened at practically the same rate; 90 per cent. of each sample had ripened by the 19th day, i.e. two days in advance of the control fruit.

The fruit from the plots treated with potash alone, on the other hand, was significantly slower in ripening, 24 days being required before 90 per cent. of the fruit had ripened, i.e. three days later than the control sample.

There was no appreciable difference in quality between the samples, all the fruit when ripe was of a good, even, red colour and the texture and flavour were very good; the skins, however, were rather tough. A small but not serious amount of rotting had developed in most samples by the time all the fruit had ripened (Table X).

TABLE X.

The extent of rotting at the time when all fruits had ripened.

Sample.	Days to 100% ripe.	Rotting %.
No treatment	26	4
Nitrogen	22	4
Nitrogen + Potash	22	6
Nitrogen + Potash + Phosphate	26	0
Potash alone	28	8

The effect of ethylene on ripening.

The effect of ethylene, at a concentration of 0·1 per cent. in the air, on ripening is shown in Table XI. Ethylene at this concentration reduced the time for the completion of ripening.

The outdoor fruit which was stored throughout at 65° F. in air + ethylene ripened completely 2 days in advance of that stored in air alone. The sample of glasshouse fruit in air + ethylene ripened 9 days before that in air.

This effect, however, was not due to the acceleration of the ripening of the sample as a whole, but mainly to the increased rate of ripening of a comparatively few of the slowest ripening fruits. Most of the samples were, on the whole, affected only very slightly (Table XII).

TABLE XI.

The effect of 0·1 per cent. of ethylene in the air on the rate of ripening of tomatoes.

Treatment of sample.	Days at 65°F. to complete ripeness.	
	In air.	In air +0·1% ethylene.
Harbinger, outdoor, gathered October 12th:		
65° F. throughout	24	22
7 days at 45° F.	28	21
14 ,, ,,	21	14
21 ,, ,,	23	14
7 ,, 50° F.	23	21
14 ,, ,,	21	20
21 ,, ,,	17	17
7 ,, 55° F.	21	19
14 ,, ,,	17	15
21 ,, ,,	14	14
Market King, glasshouse, gathered October 31st:		
65° F. throughout	29	20
7 days at 45° F.	26	21
14 ,, ,,	23	20
22 ,, ,,	20	20
7 ,, 50° F.	24	15
14 ,, ,,	23	14
22 ,, ,,	22	16
7 ,, 55° F.	23	21
14 ,, ,,	16	17
22 ,, ,,	14	14

TABLE XII.

The effect of 0·1 per cent. ethylene in air on the ripening of different fruits in samples of tomatoes.

Percentage of sample ripe.	Harbinger (outdoor).		Market King (glasshouse).	
	Air + ethylene.	Air alone.	Air + ethylene.	Air alone.
	days.	days.	days.	days.
25	11	12	8	8
50	15	15	11·5	12
75	17	17	14	16
100	22	24	20	29

It is clear that in both samples some 75 per cent. of the fruit ripened at the same rate whether in air or in air + ethylene, a marked acceleration being effected in only some 25 per cent. of the fruits. Thus, the presence of ethylene tended to make ripening more uniform by its effect on certain fruits only.

In the samples ripened at 65° F. after a period of storage at a lower temperature the effect of ethylene was similar.

THE QUALITY OF THE FRUIT.

In general, the flavour and colour of tomatoes that have ripened from a green state off the plant are not quite as good as those that have completed or nearly completed their ripening on the plants. (Very small immature fruits will, of course, not ripen satisfactorily off the growing plant under any known conditions.) Furthermore, delayed ripening either by reduction of temperature or by storage in an artificial atmosphere leads to some deterioration of colour, either paleness or the development of a purple tinge. For these reasons the storage

of English tomatoes is unlikely to find favour at times when supplies of fruit ripened normally on the plant are available.

However, it has been found in the present trials that the quality of the late fruit that will not ripen on the plant was surprisingly good when it was stored and ripened under appropriate conditions ; while inferior to the normal summer home produced fruit, it was definitely superior to much imported fruit which formerly found a ready market in this country late in the year.

CONCLUSIONS.

The data presented show that green fruit of Harbinger tomatoes gathered in early September and again in mid-October from plants grown in the open-air took about 4 weeks at 65° F. to complete their ripening. At 55° F. the early gathered fruit took about 8 weeks and the late gathered about 6 weeks. These represent the periods during which a supply of ripe fruit could have been marketed. At 50° F. ripening proceeded very slowly, and at a lower temperature it was prevented. At all temperatures below a point between 50° and 55° F. the fruit became injured after a certain period of storage, so that when moved to a higher temperature, which allowed ripening to proceed, heavy wastage from rotting developed before the fruit had completed its ripening.

Market King tomatoes grown under glass ripened completely in 4 weeks at 65° F. and in 6 to 7 weeks at 55° F. ; ripening proceeded slowly at 50° F., without injury, but the colour tended to be pale.

Harbinger tomatoes were injured after being stored for 21 days at 50° F. and after still shorter periods at lower temperatures. Market King tomatoes were injured after 22 days at 45° F. or 16 days at 40° F.

These results are in agreement with earlier findings (1, 3), with fruit of slightly more advanced maturity, viz. that tomates cannot successfully be cool-stored for any great length of time. It is clear, therefore, that prolonged storage of green fruit for subsequent ripening is not possible.

The marketing period was prolonged by about a fortnight, at the most, by cool storage, the best result being achieved by storing initially at 45° F. The period at this temperature necessary to get the maximum results varied with the fruit. The minimum time before injury was caused was 14 days. For practical purposes, therefore, this period should not be exceeded.

Gas storage effectively retarded the ripening of Market King glasshouse fruit, both at 55° and 50° F. A storage and ripening period of 47 days was obtained by storing for 28 days at 50° F. in an atmosphere of 5% O_2 + 10% CO_2 + 85% N_2 and then ripening in air at 65° F. The extension of time over that for ripening at 65° F. throughout was thus 18 days. This was a better result than that obtained by cool storage in air, and there is no doubt that the period of storage could have been increased, but to what extent is not known. This method appears to be much more promising for obtaining an extension of the marketing period than cool storage alone. Further investigation is required to determine the optimum gas storage conditions.

Slightly slower ripening was obtained by leaving the fruit on the stems at 65° F., such fruit taking 5 days longer to complete ripening than detached fruit.

The rate of ripening was influenced to some extent by the manurial treatment of the plants ; the fruit from plants treated with potash alone was significantly retarded in ripening as compared with that from the unmanured and the other manured plants.

Ethylene at a concentration of 0·1 per cent. in the air accelerated the ripening of only the most slowly ripening fruits. The general effect was to make the ripening rather more uniform, but the rate of ripening of the sample as a whole was not accelerated to any great extent.

ACKNOWLEDGMENTS.

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SUMMARY.

A supply of ripe tomatoes was obtained from green, end-of-season fruits over a period of 4 weeks by keeping them at 65° F., and over a period of 6 to 8 weeks by keeping them at 55° F.

The period of supply was prolonged by about a fortnight, at the most, by storing the green fruits at 45° F. for a short time. The maximum possible storage period was 14 days.

The period of supply was further increased by storing the green fruits in an artificial atmosphere.

Slightly slower ripening was obtained by leaving the fruits on the stem.

The manurial treatment of the plants influenced, to some extent, the rate of ripening of the fruit.

The ripening of green tomatoes in air + 0·1 per cent. of ethylene was more uniform than in plain air, but the effect was on certain fruits only.

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GROWTH AND CROPPING OF APPLE TREES ON MALLING ROOTSTOCKS ON FIVE SOIL SERIES

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Introduction.

It is well known that soil type has a great effect on the growth and cropping of fruit trees, but the full potentialities of the various main soil types are still only imperfectly known and recorded. In the Kent Lower Greensand Fruit Soils Survey, Bane and Gethin Jones (1934) found that although great contrasts in tree behaviour were evident on different soils it was difficult to evaluate the exact part played by the soil itself on account of the wide diversity of age and variety of trees, the former use of unknown or mixed rootstocks, and variations in manurial and other management factors.

Earlier work by Hatton (1926, 1930), with apple trees on known rootstocks on loam, sand, chalk and clay soils, had already shown that although the general principles of rootstock effect held good for all soils, each soil had a characteristic effect on the growth and performance of the whole range of rootstocks, in some cases making a rootstock that was suitable for one soil unsuitable for another. Studies by Rogers and Vyvyan (1934) on the root systems of trees on loam, sand and clay soils showed large differences of root growth in relation to the different soil profiles. There is therefore little need to emphasize the importance of knowing the soil effects when deciding whether to use a particular soil for fruit growing, what rootstocks to plant, and what cultural programme to adopt.

In order to get such information for some of the important types of soil in Kent, similar sets of 100 trees of Cox's Orange Pippin and Worcester Pearmain apples on a range of standardized rootstocks were planted on five contrasting soil series, on all of which fruit is widely grown. The behaviour of these plots during their first ten years is described below.

Material and methods.

The five soil series, as classified and named by Lee (1931) and Furneaux (1932) were: (A) Wye Series (Brickearth, loam), (B) Rattle Series (Clay with flints, clay loam over clay), (C) Lamberhurst Series (Wadhurst clay, silt loam over clay), (D) Curtisden Series (Tunbridge Wells Sand, very fine sandy loam, of compact structure), and (E) Ladham Series (Brickearth of High Weald, very fine sandy loam, of loose structure).

A description of their main physical and chemical features is given on p. 211, below.

Plots A to D inclusive were planted in the winter of 1935-36, and Plot E in 1937-38. A sixth plot was also planted in 1937-38 on the Sutton soil series, but owing to cultural difficulties this was given up in 1940. All trees were planted as maidens, i.e. one year old.

Each set of trees contained both Cox and Worcester on the rootstocks Malling I, II, VII and IX, and Cox on Malling XVI, thus including examples of all the main rootstock vigour groups. The behaviour of M. I, II, IX and XVI at East Malling has already been the subject of full reports (Hatton, 1927, 1935). Rootstock M. VII is less well known but was included as being a very promising semi-dwarfing stock (Hatton, 1935).

The layout of each plot was as shown in Fig. 1 from which it can be seen that there were four identical sub-plots of nine trees each, with guard trees all round, having a Cox on M. XVI in the centre of each. These were planned to make a simple manurial trial possible in the future, and were roughly similar to the sub-plots of the large apple manurial trial at East Malling, in which the performance of Cox on a range of rootstocks and under various soil fertility conditions can be compared (Hoblyn, 1941). A fifth, dissimilar, plot at one end was provided for root excavations at a suitable time.

All the plots were planted on commercial fruit farms, and all except A formed part of larger areas planted at the same time, so that normal orchard operations could be carried out with greatest ease and economy.

The general cultural policy was to treat each plot so as to obtain its best commercial possibilities. The alternative, namely, to apply a rigid standard form of pruning, spraying, manuring, etc., to all plots, leaving the soil as the only variable factor, was rejected because such a standard form would actually result in wrong treatment on some plots.

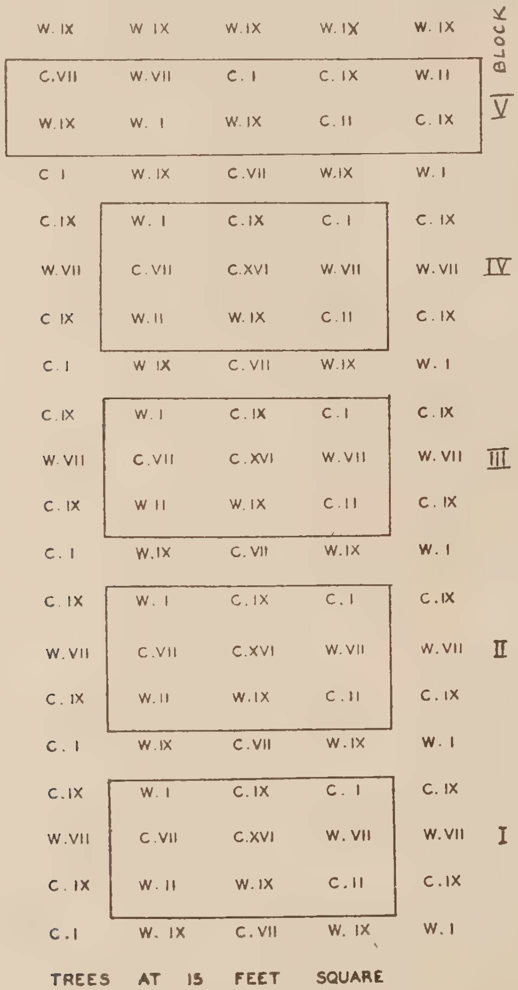

FIG. 1.

Planting plan used for each of the plots. C—Cox's Orange Pippin; W=Worcester Pearmain. The Roman numerals following the letters show the rootstock numbers. The lines enclose the blocks of main experimental trees.

Each grower was asked to apply such sprays as were necessary for good control of pests and diseases. The pruning was done throughout by the Research Station or the County staffs, or under their direct supervision. Sulphate of potash, at the rate of 3 cwt. per acre, was applied to all plots each year from the time of planting to the spring of 1940 to ensure that potash deficiency was not a limiting factor. Actually no differential cultural or manurial treatment was given for the first seven years, but when in 1942 it was found that on Plot C excessively vigorous growth was continuing and that Canker was proving very troublesome, a cover crop

consisting of perennial ryegrass and broad red clover was sown on this plot to check the growth. In 1943 it was considered that the growth on Plot E also required a mild check, and a cover crop of 6 lb. broad red clover, 1 lb. wild white clover and 1 lb. New Zealand white clover per acre was sown in the spring. Dressings of nitrogen, of the order of 3 cwt. nitro-chalk per acre per annum, were given to these grass plots. The other plots were clean cultivated during the period under review. It will of course be realized that the final results are therefore due not to the soil alone, but to the whole programme adopted with a view to extracting the best potentialities from the soil.

The trees were grown as open centre bush trees and from the third year onwards the pruning method known as the "renewal" system was adopted (Thompson, 1943). In this work the Kent County Horticultural Staff, Mr. W. G. Kent, Mr. C. R. Thompson and their colleagues, gave very valuable and welcome help. The exact treatment of the trees on each rootstock was decided each year after inspection of their growth. At this time length of leader tipping, proportion of one-year-old laterals to be cut out and amount to be removed from two-year-old laterals were considered. Under the general policy, the pruning was modified for each rootstock on each soil to secure as good a balance as possible between growth and fruiting. Thus, apart from thinning out and spacing of shoots, the more vigorous the growth the lighter was the pruning and the higher the proportion of shoots left uncut. This naturally tended to compress the rootstock effects to some extent by bringing the trees on vigorous rootstocks into earlier cropping. The general treatment of leaders and laterals was as follows:

Leaders.—On most plots the leaders were tipped each year, the length removed varying from a quarter to a half according to the vigour of the trees, except in the first year when about two-thirds to three-quarters was removed. On Plot A, however, the Worcesters were left untipped for one year in 1941, and the Cox trees on M. XVI on the same plot were untipped from 1942 onwards, as the trees were growing very vigorously.

Maiden Laterals.—Maiden or one-year-old laterals which were rubbing, crossing or competing with the main leader were cut right out close to the main stem. With Cox, from one-third to one-half in number of the remaining laterals were cut back to about three inches and the others left full length. With Worcester all the remaining laterals were left full length except where the trees were particularly well furnished with fruit buds.

Two-year-old Laterals, which had been left unpruned the previous year, were cut back to a fruit bud, from one-third to half the two-year-old wood being removed.

Spurs.—From 1941 onwards some of the spurs on the Cox trees on M. IX were shortened to two good fruit buds per spur.

The vegetative vigour of the trees was measured in the early years by (i) the length of new shoots, (ii) the number of prunings, and (iii) the girth of the trunk at 9 in. above the union between rootstock and scion. A record of height and spread of branches was made in 1943. Measurement of the girth of the trunk was continued regularly throughout the period under review, but owing to the distance of the plots from the Station it was not practicable to make such full records of wood growth and prunings as are normally made at the Research Station.

Fruitfulness was measured by counting the apples on each tree shortly before picking time, since it was impracticable to obtain weight of fruit per tree on these outlying plots.

Leaf drop and marginal and interveinal leaf scorch were recorded in 1939 and 1942. Records of Canker were made every year.

Analyses of soil samples from each plot were kindly made by Dr. N. H. Pizer, of Wye College, in May, 1941. The following methods of examination were used: Texture, by feel; pH, by glass electrode; available potassium and phosphorus, by modified Morgan procedure; organic matter, carbon $\times$ 1·724; carbon, by method of Walkeley; nitrogen, by Kjeldahl.

SOIL SERIES AND SITES OF PLOTS.

A. *Wye Series* (*Brickearth*).

This is a deep alluvial soil which extends to great depths and is widespread in the famous Sittingbourne fruit area. The experimental plot at Faversham was on practically level ground at a height of 140 ft. above sea level. The profile of the plot showed about 10 in. of dark brown brickearth loam, becoming lighter in colour and slightly sandier towards 36 in. Few stones

were present. Drainage was good. The soil was calcareous and alkaline down to 3 ft. The available phosphorus was fairly high. The available potassium was extremely high in the top 6 in., moderate in amount from 6 to 12 in. and low from 12 to 36 in. On Plot A, and on all other plots, the amount of nitrogen was low and decreased with the organic matter. In the surface layers the organic matter was low on all plots, even in the heavier soils which usually contain much more than the lighter soils, and it decreased rapidly in amount below the top 6 in. The carbon : nitrogen ratio indicated that the organic matter was in an advanced state of decomposition contributing very little to the nutrition of soil organisms or plants.

B. *Rattle Series* (*Clay with flints*).

This soil, which overlies chalk, is widespread in north Kent, though with considerable variations in its depth and in the amount of flint. The experimental plot at Bicknor was nearly flat at a height of 400 feet above sea level with good air drainage to the north. Very numerous flints on the surface and throughout the soil were a feature of this plot, in fact it was impossible to dig it with a spade. There was about 9 to 12 in. of clay loam of medium brown colour passing into reddish clay at over 36 in. Drainage was satisfactory. This soil, like that of Plot A, was calcareous and alkaline down to 3 ft. The available phosphorus was fairly high ; the available potassium relatively high in the top 6 in. (though much lower than in A and C), but low from 6 to 36 in.

C. *Lamberhurst Series* (*Wadhurst Clay*).

This series is one of the Hastings Beds soils derived from clay. The experimental plot at Horsmonden occupied the middle of a long gentle slope, facing north. The height varied from 220 to 200 ft. above sea level. The soil consisted of 9 in. of brown clayey loam, with a marked tendency to cracking, leading to whitish very fine sandy clay with manganese concretions. Some yellow mottling and white clay flakes occurred at 30 to 36 in. Drainage was fair. The soil was moderately acid at the surface, became more acid with increasing depth and was strongly acid at 3 ft. The phosphates showed a sudden drop from a moderately high amount in the top 6 in. to a low value in the deeper layers. The available potassium was extremely high in the top 6 in., moderate in amount from 6 to 12 in. and low from 12 to 36 in.

D. *Curtisden Series* (*Tunbridge Wells Sand,* of compact structure).

This is another of the Hastings Beds soils. The experimental plot at Goudhurst sloped sharply to the south-south-east. The height varied from 210 to 180 ft. above sea level. The soil consisted of very fine sandy loam, with 9 to 10 in. of darkish top soil passing into whitish and yellowish material, floury to the touch, becoming siltier and more compact with increasing depth. The very close structure of this soil actually made it appear heavier than a loam, and caused slightly impeded drainage, which is a typical feature of this Series.

The soil was alkaline at the surface and very slightly alkaline below ; it may have been limed at some earlier date as it is unusual for soils of the Curtisden Series to have such a high pH value. Phosphate was medium to high near the top and only moderate in amount in the lower layers. Potassium was lower on this plot than on any of the others, being classed as low in the top 6 in. and very low from 6 to 12 in. Soil erosion was visible in parts of the plantation but was not important on the experimental plot.

E. *Ladham Series* (*Brickearth of the High Weald*).

This is a brickearth on the Hastings Beds, with about 24 in. of light yellow-brown very fine sandy loam, clean to handle, becoming a medium brown and of looser texture from 24 to 36 in., with practically no stones. The experimental plot, at Horsmonden, sloped to the south from 220 to 200 ft. above sea level, with good air drainage. Drainage was good. The soil, which was a little shallower at the top (north) end, was moderately acid at the surface and became less acid with increasing depth. The phosphate was medium to low, but uniformly distributed throughout the various layers. The potassium was moderately high in the top 6 in. but from 6 to 36 in. it was low.

It should be noted that the contrasts between tree behaviour on the different plots were

due not only to the soils, but also to the site effects including wind, frost and rainfall, and probably to some extent to differences in spraying and cultivation by the different owners. Thus the effects hereafter described as " soil and site effects " are actually composite effects of soil, site and management. Some attempt will be made to evaluate these various factors in the final discussion.

Results.

1. *Tree Growth.*

(*a*) ***Height and spread of branches and cross sectional area of trunk.***

(i) *Soil and site effect.* In each case the general effect of the soil and site will be described first, followed by the particular reactions of different rootstocks and varieties. Fig. 2 shows diagrammatically the mean height and spread of the various trees in 1943, at the age of 8 years

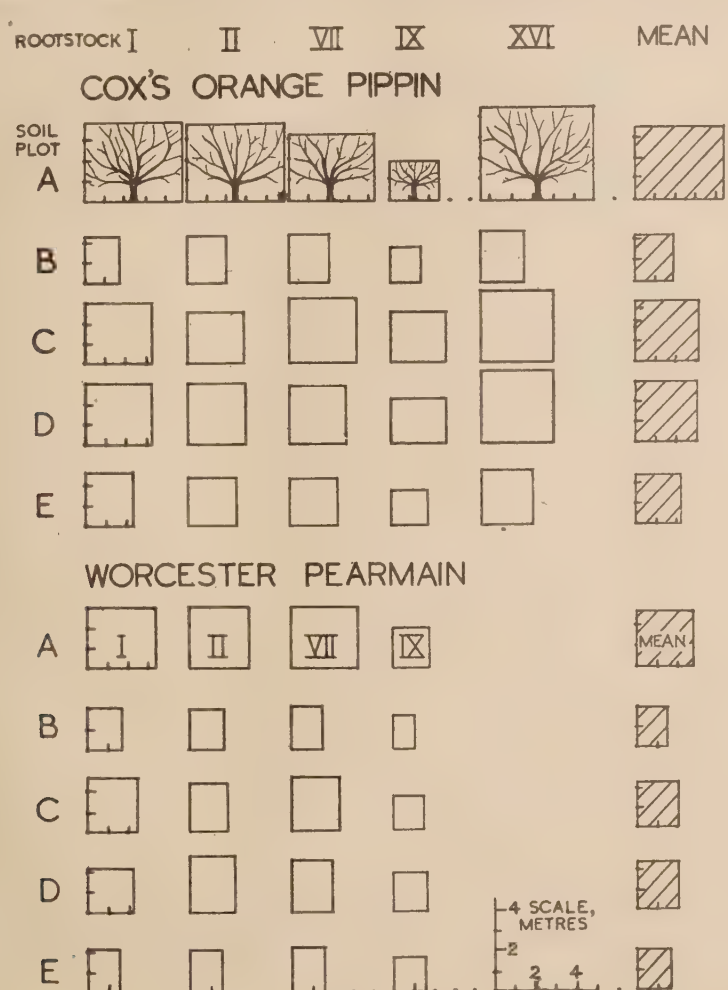

Fig. 2.

Mean height and spread of trees on different rootstocks and soils, January, 1943. Age of trees on Soil Plots A, B, C, D, 8 years; and on Plot E, 6 years.

for plots A, B, C and D, and 6 years for plot E. The contrasts are also seen in the photographs (Plates II-IV). The great difference between Plot A (Brickearth) and Plot B (Clay with flints) is evident. A has given excellent growth throughout, and its fine healthy, well-developed trees have borne eloquent testimony to the good nourishing powers of the deep brickearth soil under conditions of good management. This is typical of much of the Sittingbourne area,

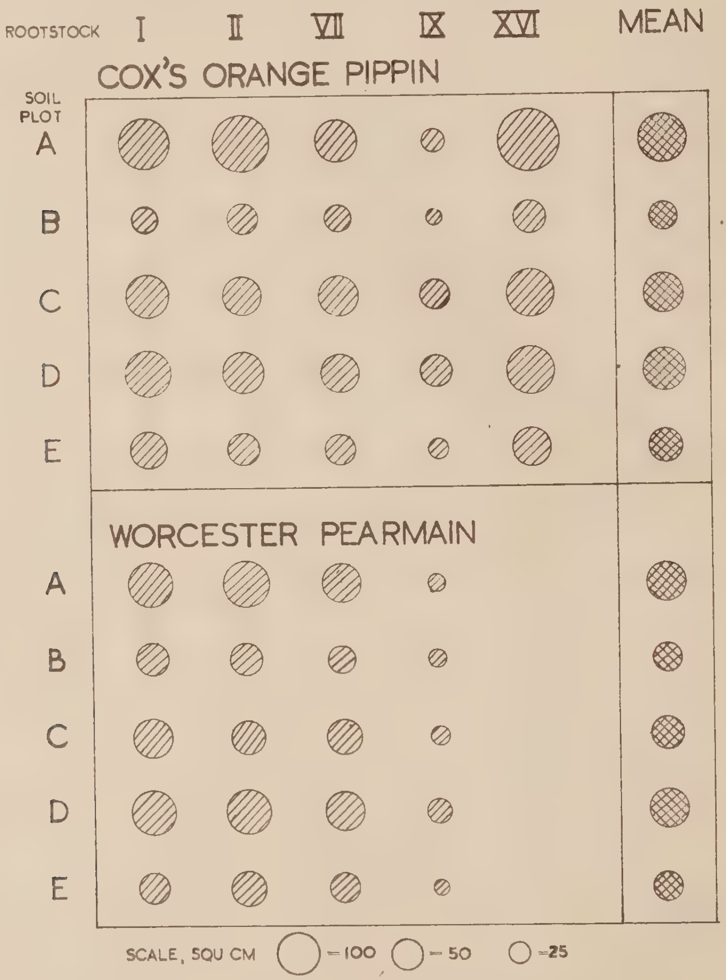

FIG. 3.
Cross sectional area of trunk of trees on different rootstocks and soils, autumn, 1945.
Age of trees on Plots A to D, 10 years, and on Plot E, 8 years.

where the soil is so deep that it is possible to find orchards planted in fields from which several feet of earth have previously been removed for brickmaking, and even under such conditions making good growth. Plot B, on the other hand, has produced markedly poor trees, especially of Cox. The Cox trees there were even smaller than those of Plot E which were planted two years later. Plots C and D produced, on the average, trees of normal size intermediate between those of A and B. (Figs. 5-8, Plates II and III.)

Fig. 3 summarizes the comparison between the soils, rootstocks, and varieties in trunk cross-sectional area. The trunk cross-sectional area has been found to be roughly proportional

to the weight of head of the tree and so gives a good single measure of size. Here again, the Cox trees on Plot B are shown to be smaller than these on the younger Plot E. This record also shows the general vigour of Plot A and the good average growth on C and D.

A statistical comparison of the soil, rootstock and variety effects was made in 1943. The numerical data used for the analyses were transformed to their logarithms (Pearce, 1943). The differences between soil plots in cross-sectional area of stem are shown below. All are significant at the $P=0\cdot001$ level.

Cross-sectional area (sq. cm.) of stem of trees on different soil plots, 1943.

Soil Plot	B.	C.	D.	A.
	28·35	46·70	56·25	78·10

Thus, so far as tree size after eight years is concerned, A had undoubtedly the best growth conditions, B the worst, while C and D had intermediate conditions, D being better than C. The conditions for E were better than those for B and probably than those for C and D, but the figures were omitted from the analysis as the trees were two years younger.

(ii) *Rootstock and variety effect.* Some interesting contrasts in rootstock influence are seen in the height and spread of branches and cross-sectional area of trunk (Figs. 2 and 3). On all soils M. IX gave the smallest trees in height and spread of branches, as might be expected. On Plot A (Brickearth) trees on M. IX were especially small in relation to those on the other rootstocks and were even smaller than those on Plots C and D. The reason for this is not yet fully apparent for on some other good soils M. IX makes considerably larger trees than those on Plot A. On Plot A, with Cox, M. XVI gave much the largest trees in height and spread. Those on M. I and II were almost exactly similar in size, and those on M. VII rather smaller. The same contrast shows well in the trunk cross-sectional area. With Worcester, trees on M. I, II and VII were very much alike in height and spread, though those on M. VII were smaller in trunk cross-sectional area.

On Plot B (Clay with flints) a different picture is seen ; with Cox, M. I, II, VII and XVI have all produced trees of much the same size in height and spread (Fig. 2). In trunk size, trees on M. XVI were slightly larger than those on M. II, and those on M. II than those on M. VII and I ; those on M. IX were again the smallest. Trees on M. I, II, VII and XVI had only about two-thirds the height and less than half the spread of the corresponding trees on Plot A. The difference on M. IX was less, the trees being nearly as high as those on Plot A, but having only about half the spread and half the trunk cross-sectional area. It is interesting to find that trees on the most vigorous rootstocks suffered most from the poor conditions. Comparing trunk cross-sectional area, trees on M. XVI on Plot B were one-quarter the size of those on A, trees on M. VII were one-third, and trees on M. IX half the size (Fig. 3). The differences with Worcester were similar in kind, but smaller in amount. The general stunting of growth is seen in Plate II, Fig. 6.

On Plot C (Wadhurst Clay), with Cox, M. VII and M. XVI had given larger trees than M. I in height and spread in 1943, and M. II had behaved as a semi-dwarf. Both Cox and Worcester trees on M. II were definitely smaller than those on M. I. The Cox trees on M. IX were larger than the corresponding trees on Plot A, in fact they were the largest M. IX trees in the experiment (Fig. 2 and Plate III, Fig. 7). The Worcester trees on M. IX were slightly smaller than those on Plot A, however. By 1945 the trunk size records showed that the trees on M. VII were smaller than those on M. I, illustrating the characteristic behaviour of M. VII which induces vigour in the early years and later diminishes the vegetative growth when fruiting increases (Fig. 3).

On Plot D (Tunbridge Wells Sand) (Fig. 2 and Plate III, Fig. 8) the contrasts were rather similar to those on Plot C, with the interesting exception that trees on M. VII were well below those of M. I in trunk size, both with Cox and Worcester, even by 1943, and Cox on M. II was definitely smaller in growth than on M. I.

The trees on Plot E (Brickearth) had not reached quite such a contrasting stage of development in six years growth (Fig. 2 and Plate IV, Fig. 9), and even at eight years old (Fig. 3) trees on M. I, II and VII were similar in trunk size ; M. IX produced, as usual, the smallest with both varieties and M. XVI the largest.

Considering rootstock effect for Plots A and D taken together, a statistical analysis of trunk cross-sectional area in 1943 showed that trees on M. XVI were significantly the largest, those on M. I and II came next ; and when all the plots were taken together there was no significant difference between the growth on these two rootstocks. Trees on M. VII were significantly smaller than those on M. I and II and trees on M. IX significantly the smallest. The rootstock effect was most marked on the most fertile soil, i.e. on Plot A, less so on B and C, and least on Plot D.

On the whole, the growth of Cox was greater than that of Worcester except on Plot B where there was very little difference in size between the two varieties. The rootstock effect was more marked with Worcester than with Cox ; e.g. with Worcester the trees on M. II were three-and-a-third times as big as those on M. IX, whereas with Cox they were only two-and-a-half times as big. The extent of these contrasts is shown below.

Cross-sectional area of stem of Cox and Worcester on different rootstocks, 1943.

Rootstock	IX.	VII.	II.	I.	XVI.
Cox	26·5	54·9	66·4	65·8	90·7
Worcester	16·8	46·8	55·0	56·7	—

P=0·01.

(*b*) *Number of prunings and new wood growth.*

The number of prunings, recorded from 1936 to 1939, was found to vary from soil to soil according to vigour of tree growth (Table I). One interesting point that should be noted, however, is that the number of prunings did not in general vary greatly from stock to stock within a plot, although the size of tree was so markedly different, as already shown by other vigour records. This was doubtless largely due to the light pruning method used, in which a relatively larger proportion of laterals was left uncut on vigorous than on weak trees.

TABLE I.

Mean number of prunings per tree per year (1936-39).

Cox.	Rootstock. I.	II.	VII.	IX.	XVI.	Mean I to XVI.	Mean I to IX.
Plot A	26·0	28·6	27·7	19·5	30·9	26·5	25·5
„ B	16·4	18·2	18·2	15·5	20·4	17·7	17·1
„ C	21·7	17·7	22·8	20·8	23·6	21·3	20·8
„ D	21·5	20·9	20·3	23·0	24·7	22·1	21·4
Mean	21·4	21·3	22·3	19·7	24·9	21·9	21·2
Worcester.	**Rootstock. I.**	**II.**	**VII.**	**IX.**			**Mean I to IX.**
Plot A	15·2	15·3	17·0	10·8			14·6
„ B	13·7	11·6	12·2	9·9			11·8
„ C	14·0	8·1	11·9	9·4			10·8
„ D	17·7	14·4	11·1	11·2			13·6
Mean	15·2	12·4	13·1	10·4			12·7
General Mean Cox and Worcester ..	18·3	16·9	17·7	15·0			17·0

The number of prunings of Cox was in general considerably higher than those of Worcester, reflecting the less twiggy habit of the latter variety and the fact that relatively fewer shoots of Worcester were pruned, on account of its tip-fruiting habit. Even on Plot B, where by 1944 there was hardly any difference in size between the Worcester and the Cox trees, the number of prunings in the first four years was less with Worcester than with Cox.

TABLE II.

Mean wood growth per tree and mean length per shoot (cm.), 1936.

Cox.	Rootstock. I.	II.	VII.	IX.	XVI	Mean I to XVI.	Mean I to IX.
A	249 *47*	253 *39*	310 *48*	150 *26*	338 *48*	260 *42*	240 *40*
B	186 *32*	262 *29*	239 *34*	142 *27*	249 *26*	216 *30*	207 *31*
C	152 *27*	99 *26*	129 *26*	107 *32*	133 *31*	124 *28*	122 *28*
D	209 *40*	222 *40*	137 *30*	167 *42*	260 *40*	199 *39*	184 *38*
Mean	199 *36*	209 *34*	204 *34*	141 *32*	245 *36*	200 *35*	188 *34*
Worcester.	**Rootstock. I.**	**II.**	**VII.**	**IX.**			**Mean I to IX.**
A	97 *19*	112 *22*	204 *35*	59 *31*			118 *27*
B	118 *20*	97 *18*	107 *21*	68 *19*			97 *19*
C	47 *21*	28 *28*	47 *20*	50 *25*			43 *23*
D	160 *29*	109 *33*	146 *42*	96 *26*			128 *32*
Mean	105 *22*	86 *25*	126 *30*	68 *25*			96 *26*
General Mean .. Cox and Worcester..	152 *29*	148 *29*	165 *32*	105 *29*			142 *31*

Figures for wood growth are in ordinary type, and those for mean length of shoot in italics.

Measurements of new wood growth made in 1936 are shown in Table II. The main interesting feature was that the wood growth on Plot B, subsequently the weakest plot, was markedly greater than that on Plot C. Trees on M. XVI made the most shoot growth and those on M. IX the least. It is interesting to note that the semi-dwarfing rootstock M. VII induced greater growth in the early years than did M. I or II, and that it was only after about five years that trees upon it began to fall below the others in size. The wood growth of Cox was greater than that of Worcester in 1936, including Plot B where the Worcesters were eventually about the same size as the Cox trees. The mean length of shoots was calculated from the number and length of shoots measured, and showed that the shoots were longest on Plots A and D, and shortest on B and C (Table II). Differences in length of shoot, between trees on different rootstocks, were not very great. The Cox shoots were much longer than those of Worcester.

2. *Crop.*

(*i*) *Soil and site effect.* There was great difference in cropping between the different plots. The average crop per tree each year and for the whole period—taking both varieties and all rootstocks together—is shown for each plot in Table III. This shows that over the whole period

TABLE III.

Mean number of apples per tree (taking both varieties and all rootstocks together), 1938-45.

Plot.	1938.	1939.	1940.	1941.	1942.	1943.	1944.	1945.	Total.
A	1	16	81	117	236	310	764	834	2,359
B	0	3	1	0	19	63	189	76	351
C	0	4	13	2	56	94	27	17	213
D	0	10	5	0	8	41	32	114	210
E*	0	0	0	1	6	40	12	187	246
E†	0	1	6	40	12	187			

* Two years younger than A-D.
† Crop of Plot E *at similar age* to the other plots, i.e. its crop two years later.

TABLE IV.

Mean total number of fruits per tree, 1936-43.

	Rootstock.					Mean	Mean
Cox.	I.	II.	VII.	IX.	XVI.	I to XVI.	I to IX.
A	1075	1130	1136	550	832	945	973
B	31	51	28	125	1	47	59
C	116	268	107	173	64	146	166
D	25	52	8	100	1	37	46
E*	17	15	42	68	1	29	35
Mean A to D ..	312	375	320	237	224	294	311
	Rootstock.						Mean
Worcester.	I.	II.	VII.	IX.			I to IX.
A	1065	830	842	434			793
B	152	183	93	77			126
C	267	158	216	136			194
D	31	24	102	80			59
E*	62	30	12	57			40
Mean A to D ..	379	299	313	182			293
General Mean Cox and Worcester A to D	345	337	316	209			302

* Two years younger.

Plot A with its good soil and high standard of culture bore six times as much fruit as any of the other plots, and also that its crop increased continuously from year to year (Fig. 4. Plate I). Thus it was entirely free from biennial or irregular bearing, and this in spite of the fact that, over much of Kent, serious frost damage occurred to fruit blossom in the years 1938, 1941 and 1944,

and in some parts in 1945. The Faversham area, containing Plot A, certainly did not entirely escape frost damage, but there was evidently enough blossom left undamaged on Plot A to ensure a valuable crop even in these years. The trees on Plot A were not only the largest as shown above, but also apparently made the most efficient use of the space occupied, since the crop per unit area of trunk cross section was much higher on this plot than on the others. This was true both for the crop in the tenth year (Table VI) and for the mean total crop per unit area of trunk cross-section.

Since the trees were planted at 15 ft. square (193 to the acre) the figures for number of apples per tree also give a rough indication of number of bushels per acre, if it is assumed that the mean size of the fruits is about 200 to the bushel (a reasonable average). Thus it appears from Table III that Plot A, as a whole, cropped at the rate of over 700 and 800 bushels per acre in 1944 and 1945 respectively. Its actual yield was rather less, however, since its fruits could not be thinned in these years and averaged rather more than 200 to the bushel.

With regard to the cropping of trees on individual rootstocks, shown in Tables IV and V, the translation into yield per acre requires some caution. The vigorous trees on M. I, II and XVI had smaller trees interplanted between them (Fig. 1) and, on Plot A each vigorous tree already occupied more than a 15 ft. square by 1944; in fact, by 1946, the branches were beginning to meet in the rows and removal of alternate trees was becoming desirable. Nevertheless, even if this is done, leaving the vigorous trees at approximately 20 ft. square, a crop of 2,000 average fruits per tree would produce about 1,000 bushels per acre, and this seems by no means unlikely under such conditions.

Plot B, although having the smallest trees, comes second in order of crop—though far behind A—for the whole period (Table III). This is largely because it bore a fair crop in 1944, when plots C, D and E were all seriously affected by frost. Before 1944 its crop was below that of Plot C, but above that of Plot D (Table IV).

TABLE V.

Mean total number of fruits per tree, 1944-45.

Cox.	Rootstock. I.	II.	VII.	IX.	XVI.	Mean I to XVI.	Mean I to IX.
A	3796	3469	1565	323	4646	2760	2288
B	292	384	262	251	162	270	297
C	11	15	42	26	57	30	23
D	103	186	62	109	42	100	115
E*	126	204	115	94	59	120	135
Mean A to D	1050	1013	483	177	1227	790	681
Worcester.	**Rootstock. I.**	**II.**	**VII.**	**IX.**			**Mean I to IX.**
A	1410	1619	866	288			1046
B	425	349	336	152			315
C	58	39	102	14			53
D	176	195	282	149			200
E*	311	315	192	230			262
Mean A to D	517	550	396	151			403
General Mean Cox and Worcester A to D	783	781	439	164			542

* Two years younger.

Plot C showed signs of coming into useful cropping about 1940, but was severely affected by the frosts of 1941, 1944 and 1945 (Table III). Although Plot C had some air drainage to a small valley, there was a large slope above it down which cold air could flow and gradually accumulate. Further, its exposure to the north was disastrous in the wind-frost of 1945. Thus, although up to 1943 it held second place, by 1945 it was a poor fourth in total amount of crop. Frost was thus probably the most important factor in the poor cropping of Plot C, but there was another unsatisfactory feature, more closely connected with the soil, namely incidence of Scab and Canker. This is more fully discussed below.

TABLE VI.

Crop per unit area of trunk cross-section, 1945.*

	Rootstock.					Mean	Mean
Cox.	I.	II.	VII.	IX.	XVI.	I to XVI.	I, to IX.
A	19·0	14·5	11·4	7·9	15·4	13·6	13·2
B	1·0	1·9	1·4	5·1	0·2	1·9	2·4
C	0	0	0	0	0	0	0
D	0·9	1·7	0·6	1·7	0·3	1·0	1·2
E†	2·3	3·1	2·5	4·2	1·0	2·6	3·0
Mean A to D ..	5·2	4·5	3·4	3·7	4·0	4·1	4·2
	Rootstock.						Mean
Worcester.	I.	II.	VII.	IX.			I to IX.
A	6·2	8·3	2·7	8·2			6·3
B	4·4	4·0	3·2	3·5			3·8
C	0·4	0·4	0·8	0·5			0·5
D	1·5	1·6	3·2	5·1			2·9
E†	7·5	6·3	5·2	14·1			8·3
Mean A to D ..	3·1	3·6	2·5	4·3			3·4
General Mean Cox and Worcester A to D	4·2	4·1	3·0	4·0			3·8

* i.e. $\frac{\text{number of apples.}}{\text{sq. cm. trunk sectional area.}}$

† Two years younger.

Plot D. This plot also suffered severely from the 1941 and 1944 frosts but was little damaged in 1945. Scab and Canker were also serious on this plot. Thus it is not surprising that, in spite of its good growth, its fruit production was as poor as that of Plot C.

Plot E was affected by the 1944 frost, but bore a reasonably good crop in 1945 at the age of eight years (Table III). If the crop figures for this plot are compared with those for the other plots at the same age, i.e. two years earlier, it is seen that Plot E comes second on the list, with a total of 246 apples per tree for the first eight years compared with 761 for A, 86 for B. 169 for C and 64 for D.

The plot totals for each cropping year are shown graphically in Plate I, Fig. 4, and here the great contrast between Plot A and the rest, and the severe effect of the 1944 and 1945 frost on the results are clearly seen. The fine dotted line E_1 shows the crop on Plot E at a comparable age with the rest ; but such a comparison cannot, of course, be taken as exact owing to seasonal differences. Nevertheless, it shows that the trees on Plot E have so far cropped generally better than those on B, C and D, at similar ages.

(ii) *Rootstock and variety effect.* In the first four years trees on M. IX had more fruits than those on other rootstocks, but by the sixth year (1942) they had fallen below the others. Up to 1943, trees on M. I, II and VII had borne the heaviest total crops, but by 1944 and 1945, trees on M. XVI were well above those on the other rootstocks in crop per tree on Plots A and C (Tables IV and V).

With Cox, M. II gave a significantly greater total crop than M. I on Plots C and D, and a slightly greater crop on the other plots. The crops of Worcester on M. I and M. II did not differ significantly on any plot.

Although in 1942 the actual number of fruits on trees on M. IX was in general less than that of those on trees on other rootstocks, the number per unit area of trunk cross-section was greater. By 1945, however, Cox trees on Plot A on M. IX and VII had fallen below the others in crop in relation to tree size at the comparatively early age of ten years. This was no doubt due to the pruning method which brought the trees on the vigorous rootstocks into heavy cropping while still relatively young. On the other plots, trees on M. IX still retained the heaviest crop per unit area of trunk cross-section at ten years old, though in some cases by only a narrow margin (Table VI).

The effect of variety on cropping varied with the soil. On Plot A the Cox trees bore a much higher crop than the Worcesters, but on the other plots the Worcesters bore a little more fruit than the Cox trees (Tables IV and V).

Diseases.

The two most serious diseases were Canker (*Nectria galligena*) and Scab (*Venturia inaequalis*). The incidence of these diseases varied greatly from plot to plot, in spite of routine control measures applied by the growers. Canker was very severe on Plots B, C and D, especially D; but there was practically none on Plots A and E (Table VII). Although the cankers on the

TABLE VII.

Mean total number of Canker infections per tree, cut out in the four winters, 1942-45.*

Cox.	Rootstock. I.	II.	VII.	IX.	XVI.	Mean I to XVI.	Mean I to IX.
A	5	5	1	0	2	2·4	2·5
B	69	58	79	27	151	76·8	58·2
C	94	54	84	39	147	83·6	67·7
D	171	61	113	26	252	124·6	92·7
E†	1	5	2	1	3	2·4	2·2
Mean A to D	84·7	44·5	69·7	23·0	138·0	71·8	55·3

Worcester.	Rootstock. I.	II.	VII.	IX.		Mean I to IX.
A	10	9	14	0		8·2
B	64	78	74	42		64·5
C	41	22	64	21		37·0
D	78	99	75	50		75·5
E†	3	0	4	2		2·2
Mean A to D	48·2	52·0	56·7	28·2		46·3
General Mean Cox and Worcester A to D	66·9	48·2	63·2	25·6		50·8

* The numbers refer to Cankers large enough to girdle three-year-old wood, or larger.

† Two years younger.

experimental trees were very carefully cut out each winter, numerous fresh infections appeared during the years 1942-45. Some of these, especially on Plots B, C and D, undoubtedly came from surrounding trees under commercial cultivation, in which the degree of effectiveness of cutting out was severely limited by wartime labour problems. Nevertheless, as all the trees were presumably healthy at the time of planting, the differences observed are fairly certainly related to the soil and the type of shoot growth produced by it, coupled, of course, with the climatic and cultural conditions of the plot.

In the plots where Canker infection was serious, trees on M. XVI were much more severely affected than those on other rootstocks (Table VII). This has also been found at East Malling (Moore, 1934), and elsewhere. Trees on M. IX were much less affected than others, perhaps because they reached maturity, as shown by relatively heavy cropping, more quickly, though even at this stage some Canker infection occurred. Cox on M. II was less affected than Cox on M. I.

In general, the varieties Cox and Worcester were about equally affected by Canker. In the early years it was worse on Cox than on Worcester on Plot B, but the tendency was reversed later. On Plot D, Worcester on M. IX was markedly more affected than Cox on M. IX.

Apple Scab was prevalent in some years, and was particularly bad on Plots B and D, where effective spray measures were not carried out in the early years. There seems some evidence that the lack of Scab control favoured the incidence of Canker.

Marginal leaf scorch was observed on Cox on Plots B and D in 1939, and on Plot E in 1942. The leaves were only slightly affected on Plot B, but were severely scorched on trees on M. I, II, and VII on Plot D. This fits in with the low potash status shown by the soil analysis.

Wind damage to leaves was observed in some seasons on Plot B, which lay in a rather exposed situation. Incidentally it is clear that although the development of Scab and Canker may be favoured by dank, humid conditions, a windy situation alone is no effective safeguard against infection by these diseases.

Discussion and conclusions.

This study has provided new data on the behaviour of Cox and Worcester on standardized rootstocks growing on different soils. Some rather unexpected contrasts and some particular suitabilities have been shown. Soil, site, rootstock, variety, management, and disease have all proved to be important factors in the final result.

While, in general, the order of vigour of trees on the various rootstocks is similar to the order given in previous trials, the range of tree vigour induced by the most dwarfing to the most vigorous rootstocks, as well as the actual size of tree produced on a given rootstock, has varied greatly from plot to plot. The range of differences induced by rootstock has been greatest on the fertile brickearths and much less on the less fertile clays and silts. On the best brickearth (Plot A) the ratio of trunk size of trees on the most vigorous (M. XVI) to those on the least (M. IX) was 6 : 1, while on the more compact soils (Plots C and D) it was only 3 : 1. Moreover, on the latter soils where the trees on M. XVI were smaller than those on Plot A, the trees on M. IX were larger than those on Plot A. It appears therefore that the conditions on Plots C and D did not offer scope for the most vigorous rootstocks to develop their full potentialities, but trees on the less vigorous rootstocks, especially on M. IX, were still able to do relatively well. The importance of such knowledge in relation to the choice of rootstocks is evident.

It must not be assumed, however, that the soil was the sole cause of the observed differences, though it was undoubtedly a powerful factor. Disease, which is probably related to both soil and management, had a great effect. Apple Canker had especially severe effects on Plots B, C and D—the more compact soils—and on these plots the trees on vigorous rootstocks were very severely affected. Thus on these soils a particularly careful choice of rootstocks and of disease control measures are desirable.

Some comparison of cropping is available although the trial has been in progress for only ten years. Maturity as indicated by comparatively heavy fruiting, was reached on some plots at about eight years old, even with the vigorous rootstocks. This was largely owing to the light pruning method used. Once the trees had reached maturity there was, in general,

a direct relation between tree size and amount of crop. It is obvious, however, that total crop is also related to factors other than size of tree, since Plot B on which the trees are smaller than on any other plot has produced more fruit than any plot except A. This is largely due to relative freedom from frost damage. There is also little doubt that the presence of severe Scab and Canker contributed to the poor cropping of Plots C and D and, in some years, of Plot B.

Differences in total crop from plot to plot were very great. In ten years these identical sets of trees, planted on five important soil series, on all of which fruit is widely grown, have produced total yields ranging from about 210 to 2,350 bushels per acre. This more than tenfold increase of the best over the worst plot can obviously make all the difference between good profit and none at all. As has already been pointed out, several factors have contributed to these differences, but most of them are within the control of the grower. Rootstock, variety, soil and site are all matters of initial choice when planting. This study has emphasized the special requirements and difficulties of certain types of soil and has indicated the importance of constant attention to management and disease control from year to year.

It would, of course, be unwise to base final conclusions on only ten years records from these plots, but some provisional deductions can be drawn.

The first consideration in obtaining consistent and heavy crops appears to be choice of a site in which incidence of frost is not severe. Next, of the soils tested, the good Brickearths appear to offer the best results. The clays and other compact soils tested can grow good trees, but special measures may be necessary to combat diseases such as Canker.

Choice of a suitable rootstock will contribute largely to success. It can be reported that M. II and M. I have given good results with Cox and Worcester as bush trees on all the soils. On the whole, M. II has been a little better for Cox. M. I has shown to slightly better advantage on the heavier soils, with the variety Worcester. M. XVI on Wye Series Brickearth has given good very large bush trees which, under the " renewal " pruning system, became very fruitful in eight years. This stock would probably be a risky one to use on the clay and compact loam soils of the Hastings Beds, on account of the greater liability to Canker.

M. VII produced fruitful semi-dwarf trees on the best soil, while on other soils trees on M. VII were nearly as large as those on M. II, but rather less fruitful, up to ten years old. Under the prevailing conditions trees on M. IX made more suitable " filler " trees in most cases.

Of all the rootstocks tested, none has given more consistent results than the very dwarfing M. IX. Though this stock has the most exacting requirements in some ways—for trees on it must be adequately staked to carry heavy crops—paradoxically it has proved the most tolerant in others, and trees on it have withstood exposure to disease, and frost in quite a remarkable manner. Trees on M. IX would probably not be recommended for commercial bush tree culture under conditions where trees on M. II and M. I can be grown satisfactorily, but for difficult conditions trees on M. IX seem to have a unique value—not least because of their marked degree of resistance to Canker infection, once they have reached the fruiting stage. Thus on the clays and similar soils, and of course for garden culture, M. IX seems worth special consideration.

In view of the fact that according to popular opinion Worcester is a relatively easy variety to grow and Cox rather difficult, it is interesting to note that in general the Cox trees were bigger than the Worcesters, and that on the best soil they bore heavier crops than the Worcesters, while on the other soils there was only a slightly higher crop on the Worcester than on the Cox trees.

If the performance of some of the plots has so far proved poor, this is perhaps hardly surprising ; for, with the Battle of Britain being fought over them, conditions for the perfect management of difficult soils have been even more difficult than usual. There can be little doubt that the conditions and performance are similar to those of many other plantations in surrounding areas.

It is of course realized that this unique set of plots has not yet told its full story, and if records on them can be maintained new information should appear. The first ten years of the life of an apple plantation, as here reported, are of great interest and importance, both to the scientist and the grower ; but the next ten years should see the trees reaching their full crop per acre and give a still better index of the potentialities of the soils concerned.

SUMMARY.

Trials of Cox's Orange Pippin and Worcester Pearmain apples on standardized rootstocks on five Kent soil series have given quantitative data showing that choice of soil and site, and of rootstock, variety, and disease control measures in relation to soil, are of fundamental importance ; and that, even with soils commonly used for fruit growing, success or failure may depend entirely on one or more of these factors, which are largely within the control of the grower.

The soils were : Plot A, Wye Series (Brickearth) ; Plot B, Rattle Series (Clay with flints) ; Plot C, Lamberhurst Series (Wadhurst Clay) ; Plot D, Curtisden Series (Tunbridge Wells Sand, a very compact soil) ; Plot E, Ladham Series (Brickearth of the High Weald).

Both Cox and Worcester were budded on the rootstocks Malling I, II, VII and IX, and Cox on M. XVI was also included.

The results up to the time the trees were ten years old were as follows :

(i) *Soil.* Soil had a great effect on growth, cropping and incidence of disease. Growth conditions were best on Plot A. Plot E had the next best growth conditions and Plot B the worst. Plots C and D were intermediate.

Contrasts in amount of fruit produced were very great, and did not follow the vigour effects exactly. Plot A had much the largest crop but Plot B, which produced the smallest trees, came second, partly owing to its having escaped spring frost damage, in some years. Plot E, which was two years younger than the others, came into heavy cropping at about the same age that Plot A did so, viz. eight years. Plots C and D produced quite large trees, but they did not bear very heavy crops. This appeared to be due to disease and frost rather than to soil, but the incidence of Canker was clearly related to soil type. Plots A and E (well-drained Brickearths) were practically free from serious diseases or leaf scorches, but Plots B, C and D (clay and compact loams) were severely affected by Canker and Scab.

(ii) *Rootstock.* Rootstock effect was greatest on the most fertile soils. Rootstock M. IX gave a very consistent performance under both favourable and more adverse conditions, producing fruitful dwarf trees which came into cropping earlier and were markedly less affected by Canker than trees on other rootstocks. The trees on M. IX were, however, soon surpassed in crop per tree by the bigger trees, which also cropped heavily while still relatively young, owing to the light pruning method used.

M. VII produced trees, in general, smaller than those on M. I and M. II, but a little too big to fill ideally the gap between M. IX and M. I and II up to ten years old.

On all the soils, M. I and II made good bush trees with little difference in size between the two stocks. Cox on M. II cropped better than on M. I, especially on the heavier soils, but there was nothing to choose between the two stocks for Worcester.

M. XVI, while giving large and fruitful trees on Plot A, was so severely attacked by Canker on Plots B, C and D as to suggest that it may be unsuitable for use on such clays and other compact soils.

(iii) *Variety.* The Cox trees were more vigorous than the Worcesters except on Plot B. On Plot A the Cox trees bore a much greater crop than the Worcesters, but on the other plots the Worcesters bore a little more fruit than the Cox trees. There was relatively little difference between the amount of Canker on the two varieties.

ACKNOWLEDGMENTS.

Grateful thanks are due to the five growers who kindly allowed these trees to be planted on their farms, and gave facilities for making the required records.

The early history of the plots owes much to the work of Mr. W. A. Bane, who was responsible for selecting the sites, with the collaboration of Mr. N. B. Bagenal and Mr. B. S. Furneaux, and for obtaining the records up to 1939.

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PLATE I.

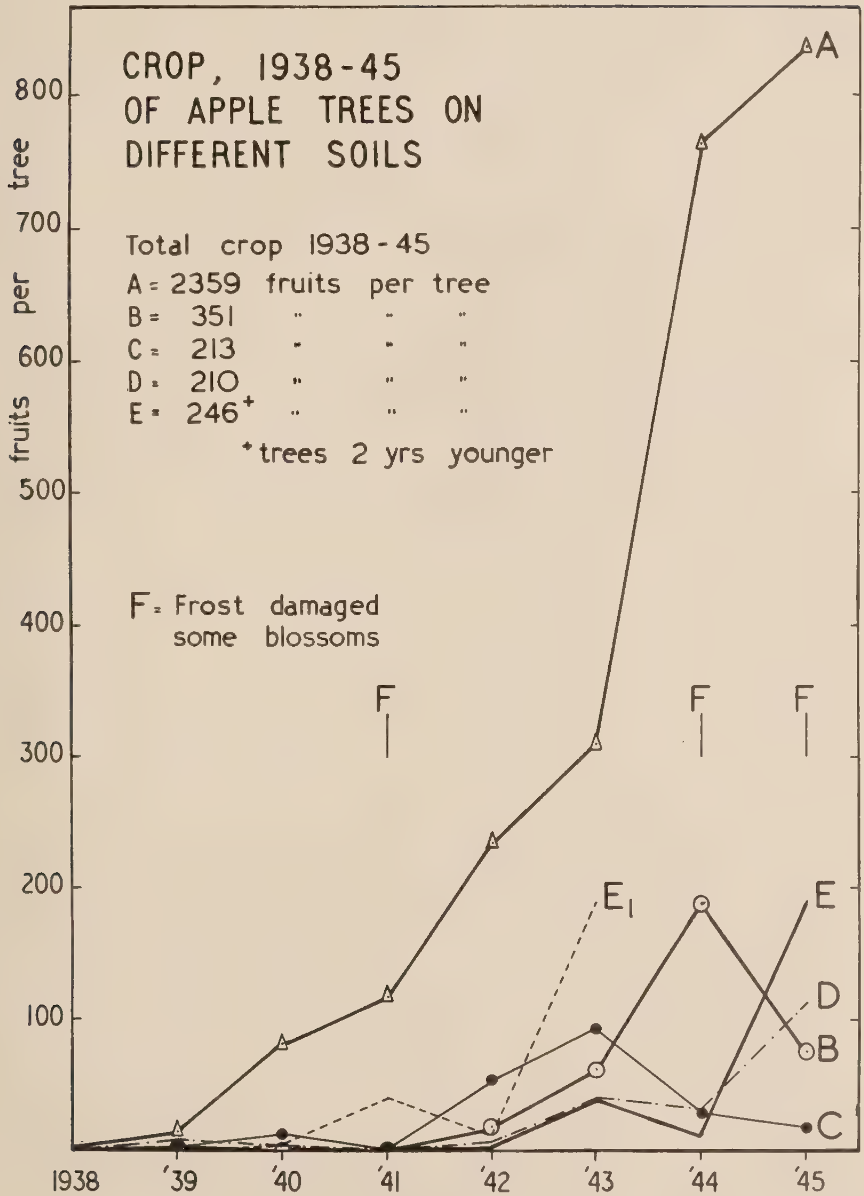
CROP, 1938-45
OF APPLE TREES ON
DIFFERENT SOILS
Total crop 1938-45
A = 2359 fruits per tree
B = 351 " " "
C = 213 " " "
D = 210 " " "
E = 246+ " " "
+trees 2 yrs younger
F = Frost damaged
some blossoms
fruits per tree
800
700
600
500
400
300
200
100
F
F
F
A
E1
E
D
B
C
1938
'39
'40
'41
'42
'43
'44
'45

Fig. 4.

FIG. 5.

Plot A (Brickearth). Cox on M. IX (left) and on M. XVI (right) at 8 years old. Note great contrast in vigour, but both are fruitful on this soil at this age. The " ropes " of blossom given by renewal pruning show well on the M. XVI. The measure is marked in lengths of 2 ft.

FIG. 6.

Plot B (Clay with flints). Cox on M. IX (left) and on M. XVI (right), 8 years old. Note great fruitfulness on M. IX, and relatively small growth on M. XVI on this soil.

Fig. 7.

Plot C (Wadhurst Clay). Cox on M. IX (left) and on M. XVI (right), 8 years old. Note more growth on M. IX, but less growth on M. XVI than on Plot A.

Fig. 8.

Plot D (Tunbridge Wells Sand, of compact structure). Cox on M. IX (left) and on M. XVI (right), 8 years old. Note vigour comparable with Plot C.

FIG. 9.
Plot E (Brickearth of the High Weald). Cox on M. IX (left) and on M. XVI (right), 6 years old. Note size of tree already greater than on Plot B at 8 years old (Fig. 6).

FIG. 10.
Plot E. Cox on M. VII (left) and on M. I (right) at 6 years old. Note medium-sized and precocious trees formed on M. VII. The grass and clover cover crop can be seen both in this picture and in Fig. 9.

Miss E. C. Thompson and Miss B. Mosse for assistance with the diagrams and photographs; and several members of the Pomology staff for recording the tree growth and fruiting.

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THE LOCALIZATION OF TOBACCO MOSAIC VIRUS IN TOMATO FRUITS

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Introduction.

Samuel (1934) found that inoculating a leaflet on a young tomato plant (prefruiting stage) with Tobacco Mosaic virus resulted in movement of the virus, first to the root and then to the shoot meristems. In fruiting plants the virus moved first to the root and the lowest fruit truss, then to the higher trusses and shoot meristems, and finally passed to the other leaves. In a private communication, Samuel has stated that all new growth made at the top of plants such as those shown in his text Fig. 5, became fully invaded with virus and showed symptoms. Symptoms always appeared in the tops of his plants unless new growth, following infection, had been checked, as for example by a pot-bound root system.

In the course of studies by the present writer on the susceptibility of fruiting tomato plants to infection with Tobacco Mosaic and Yellow Mosaic viruses, it has been observed that the failure of symptoms to appear in the developing leaves of the terminal shoot was not always associated with failure of the virus to multiply at the point of inoculation or even with failure to begin moving into other organs of the plant. Such incomplete systemic infection has been observed in plants making vigorous and rapid growth.

Kunkel (1939) stated that Tobacco Mosaic virus, when introduced through a leaf, usually moved both upward and downward on reaching the stem. Occasionally movement was downward only and at other times upward only. This work was carried out with plants from which the flowers and fruits had been removed. Tobacco Mosaic virus was sometimes found to remain dormant in the stem tissues for quite long periods.

Fulton (1941) and Bawden (1943) have both reported that Tobacco Mosaic virus may be present in high concentration in the roots of tomato and yet rarely move up into the tops. There is thus some evidence from the literature that this virus, although usually considered to induce systemic infection in the tomato, may often remain localized for varying periods in certain tissues. Some further evidence of this phenomenon will be presented in this paper.

Localization of virus in the fruit.

Under commercial nursery conditions, tomato plants at the 6-7 truss stage have been observed in which fruits of the lowest truss have been covered with brown pits, of a type associated with Mosaic infection, and yet the terminal shoot of the plant has appeared to be quite healthy and has given no reaction when tested for virus. Two examples of this have appeared under controlled conditions :

(1) 112 tomato plants growing in the ground, under glass, were inoculated with Yellow Mosaic virus on May 29th, 1946 by wiping a single leaflet with cotton wool soaked in infective juice. The plants were at the 13-14 leaf stage, with the second truss in bud. The terminal leaflet of the leaf immediately below the first truss was inoculated in all cases. (Fig. 1 (*a*).)

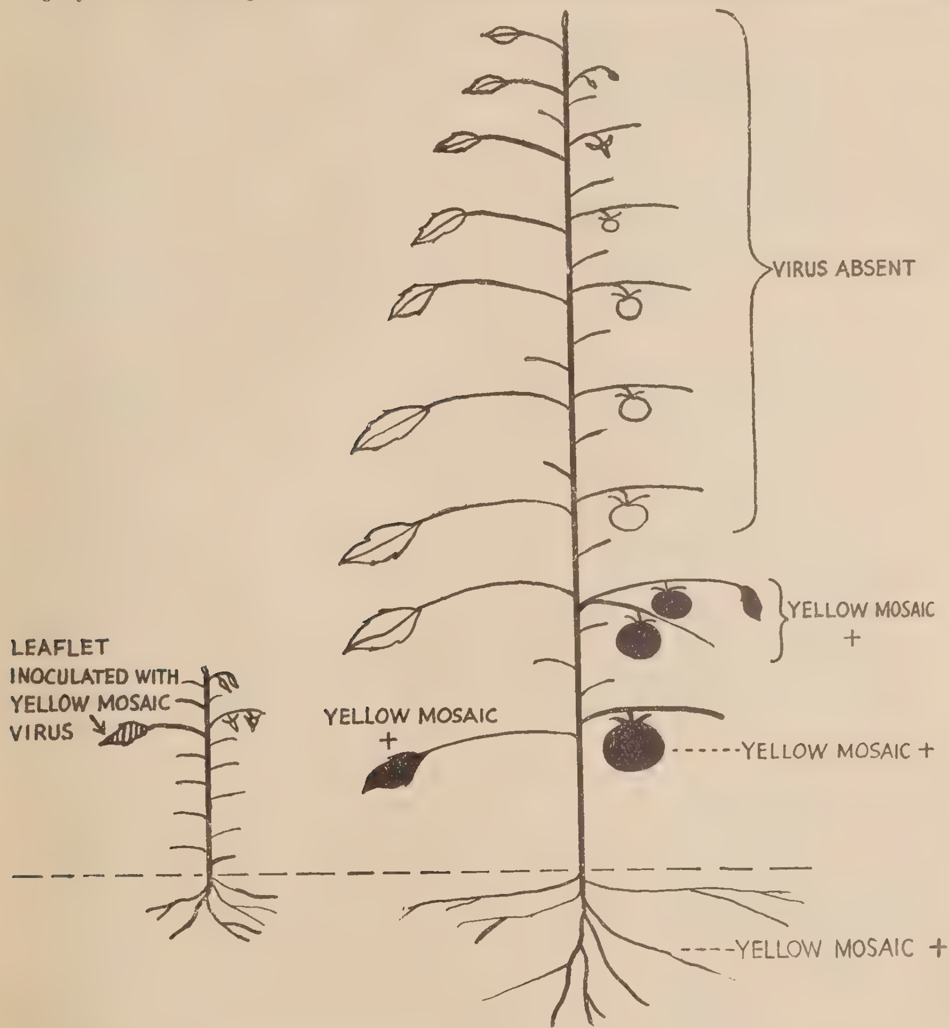
On July 2nd, 22 of these plants appeared to be virus-free, as judged by the appearance of the young leaves of the main shoot. The leaflets that had originally been inoculated were

Table I.

Condition of the original inoculated leaflet 5 weeks after inoculation.	No. of plants.
Virus-free	17
Yellow Mosaic present	1
Virus present in very low concentration (Yellow Mosaic not identified.)	4

removed on this date and tested for virus by grinding them up with a little water and wiping the juice on to leaves of seedling tomatoes and *Nicotiana glutinosa*. The result shown in Table I was obtained.

On July 16th, when eight trusses had developed, further tests were made for virus in these



(*a*) May 29th. (*b*) July 19th.

FIG. 1.

Diagram to show slow spread of Yellow Mosaic Virus following light infection in a well-grown tomato plant. Tissues containing virus on July 19th shaded black.

plants. A leaflet of the second youngest leaf of the terminal shoot and the first formed fruit of the lowest truss were tested.

Of the four plants found to contain a Mosaic virus in the inoculated leaflet (as determined by the production of local lesions), one was found to contain virus in the fruit but none had virus in the young leaves. Tests made on the plant from which Yellow Mosaic had been recovered are reported diagrammatically in Fig. 1 (*b*). Examination of the green fruits showed that those on one fork of the second truss were showing whitish blotches characteristic of

infection with the Yellow Mosaic virus. Fruits of the first truss which contained the virus were of normal appearance. The terminal shoot above the 8th truss was growing vigorously and was of healthy appearance.

(2) In an experiment carried out in 1945, tomato plants growing in ten-inch pots were inoculated with Yellow Mosaic virus when at the 18 leaf stage (three trusses in bud) by wiping infective juice on to the terminal leaflet of the second youngest leaf. Five weeks after inoculation, depressed brown lesions appeared on four green fruits of the lowest truss of one plant. At this time neither main nor lateral shoots showed any symptoms of virus infection, and tests made on these shoots proved negative. Tests made on the pitted fruits revealed the presence of a green-mottle strain of Tobacco Mosaic virus. The origin of this virus could not be ascertained, but whatever the source, the initial amount of infection must have been very slight, since all reasonable precautions against contamination by seed, smoking tobacco, leaf contact, or soil débris had been taken.

The plant was stopped between the fifth and sixth trusses on June 20th, and on July 14th a top lateral shoot developed symptoms of *Yellow* Mosaic. It was concluded that a light infection of Tobacco Mosaic virus had effectively been localized in the fruits of the lowest truss.

The influence of developing fruit on the systemic spread of Tobacco Mosaic virus.

From the foregoing observations it appeared that under certain conditions the developing fruit might effectively localize small numbers of virus particles, thereby preventing further systemic spread of the virus to the shoot meristems, with subsequent deleterious effects on the photosynthetic mechanism. To investigate this point further the following experiment was carried out :

Plant Material.—Tomato plants, var. Potentate, were planted in ten-inch pots on March 20th, 1946, when at the six-leaf stage. The pots were filled with a mixture of four parts sterilized maiden loam and one part strawy stable manure. Fertilizers were included in the compost at the following rates per pot : superphosphate 1 oz., dried blood 0·5 oz., sulphate of potash 0·2 oz., slaked lime 0·1 oz. The third truss was in bud and the lowest truss setting freely on April 13th, and on this date all pots received 10 gm. of superphosphate and were mulched with rotted pig manure. The treatments described below were given on April 17th.

Treatments.—The trusses were removed from a number of plants by cutting with a sterile knife. Some plants were inoculated with Tobacco Mosaic virus, others were uninoculated controls.

HR	All trusses removed.	Uninoculated control.
HN	Trusses normal.	,, ,,
VRB	All trusses removed.	Leaflet *below* truss 1 inoculated.
VNB	Trusses normal.	,, ,, ,, ,,
VRA	All trusses removed.	Leaflet *above* truss 1 inoculated.
VNA	Trusses normal.	,, ,, ,, ,,

Inoculation.—Leaflets of leaves either immediately above or immediately below the lowest truss were inoculated. One leaflet of the larger proximal pair was wiped three times with a cotton wool pad soaked in infective juice. The leaflets were *not* rinsed after inoculation and no abrasive was used. Infective juice was prepared by grinding up 1 gm. of fresh tomato leaflets containing Mild Tobacco Mosaic virus with water, filtering through cotton wool and making up the filtrate to 200 ml. with distilled water.

Symptom appearance.—The appearance of Mosaic mottling in the tops was noted as shown in Table II.

The appearance of symptoms in the controls at a later stage, was probably due to leaf contact—lack of space entailed close placing of the plants.

The results assembled in Table II suggest that the systemic spread of Tobacco Mosaic virus from lower leaves to the main terminal leafy shoot may be delayed by the presence of developing fruit.

On May 15th, when the roots were potbound, tests were made on 13 plants, all with trusses present, in which Mosaic symptoms had not previously been noted. A leaflet of the third youngest leaf and a mature fruit from the first truss were tested separately for virus. At this

TABLE II.

Treatment.	Number of plants showing Mosaic symptoms. Days after inoculation : 9	12	15	19	22	Total number of plants.
HR	0	0	0	0	1	4
HN	0	0	0	0	1	5
VRB	3	7	9	9	9	9
VNB	0	0	0	5	8	10
VRA	4	7	9	10	10	10
VNA	0	0	1	7	8	9

date the sixth truss was in bud and there was an exceptionally heavy first truss of fruit just turning colour. The results of these tests are shown in Table III :

TABLE III.

Treatment.	Plant no.	Mosaic symptoms in shoot.	Virus in young leaf.	Virus in fruit of truss 1.
HN	46	—	++	+++
	47	?	—	+++
	48	—	+++	+
	49	—	+++	++
	50	—	+	++
VNB	12	—	+++	++
	13	—	—	+
	14	—	—	++
	18	+	+++	+
VNA	31	—	+++	++
	32	—	+++	+++
	33	?	+++	++
	37	?	+++	+

\+ = 1 local lesion per *N. glutinosa* leaf.
++ = Few local lesions.
+++ = Many local lesions.

Thus virus was found in the fruit of the lowest truss in all those plants tested, but in three plants no virus could be detected in a young leaf taken near the top of the main shoot.

DISCUSSION.

Inoculation of all leaves of a tomato plant, at any stage of development, with Tobacco or Yellow Mosaic viruses contained in leaf juice diluted two or three times with water, usually results in complete systemic invasion of the tissues, with the appearance of symptoms in the leafy shoots. When, however, infective juice at higher dilutions is wiped on to single leaflets, localization of virus has been found to occur in the developing fruits.

In a well-grown plant it seems highly probable that the main direction of flow of elaborated food materials from the older or mature leaves will tend to be into the developing fruits and only secondarily, if at all, into the young shoots of the last-formed axis. Morphologically the inflorescence terminates the axis of the tomato plant, the main stem of the plant being made up of a succession of lateral axes. It would seem, therefore, that small numbers of virus particles may be carried with the food stream into the fruits ; and, providing growth conditions are such as to maintain a unidirectional flow of these materials, these virus particles may remain located in the fruit indefinitely, finally being removed from the system with the picking of the

ripe fruit. Where growth and development are checked as a result of unfavourable environmental factors, stopping, etc., food materials may move out of the fruit into other parts of the plant, and the virus with them.

For the effective functioning of the mechanism envisaged above, the balance between inflorescence and stem meristems would need to be maintained in every succeeding lateral axis of the sympodium, and would be dependent on satisfactory pollination and fruit development. Failure at any stage to keep the stream of elaborated food materials moving into the trusses would result in the movement of virus from the lower leaves into the young leafy shoots and also the release of virus from its secondary location in the fruits.

The potential danger to the tomato crop of smoking tobacco as a source of Mosaic infection has frequently been pointed out. When infection occurs via the hands of smokers, the amount of virus introduced into the plant must usually be very small. It is conceivable that in a well-grown fruiting plant, complete systemic invasion may often be prevented by localization of virus in the developing fruits.

SUMMARY.

1. Studies made on fruiting tomato plants have shown that Tobacco and Yellow Mosaic viruses may, under certain conditions, become localized in the developing fruits for an indefinite period.

2. An experiment was carried out in which the effect of inoculating mature tomato leaflets with Tobacco Mosaic virus was studied in fruiting plants and in similar plants from which the fruit trusses had been removed.

3. The presence of fruit tended to delay the appearance of Mosaic symptoms in the terminal leafy shoots. In some plants virus remained confined to the fruits.

ACKNOWLEDGMENT.

The author is indebted to Dr. W. F. Bewley for continued encouragement.

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A NOTE ON THE DETERMINATION OF VOLATILE SUBSTANCES FROM BRAMLEY'S SEEDLING APPLES

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SODA-LIME has frequently been used as an absorbent of the carbon-dioxide of respiration in experiments for the determination of volatile substances produced during the storage of apples and other fruits.

By Kidd and West (1938) the volatile products were measured by passing CO_2-free air over apples, then over soda-lime (to absorb the CO_2 of respiration) and finally over copper oxide heated in a combustion furnace. The emergent CO_2 was absorbed by baryta, and its amount constitutes a measure of the volatile substances produced. It was noted by these authors that when soda-lime is new it will absorb volatile substances for some time at a diminishing rate until an apparent saturation point is reached.

Walls (1942) continued this work and stated that by the above method the volatile products are likely to be partially condensed or even chemically modified by the large quantity of soda-lime used, and that consequently low values are obtained. He set out to absorb the volatile products so that they could subsequently be determined, and he found that they could be separated into two fractions :

(1) The odorous or condensable volatile products, which can be absorbed in concentrated H_2SO_4.
(2) The ethylene fraction, which is not absorbed by concentrated H_2SO_4, but which can be absorbed in activated H_2SO_4, i.e. a 2 per cent. solution of silver sulphate in concentrated H_2SO_4.

These fractions were estimated in terms of their carbon content by the wet combustion method of Birkenshaw and Raistrick (1931). Walls obtained higher values by this method than by the furnace combustion method of Kidd and West. It is not clear, however, that in using the latter method he allowed time for the saturation of the soda-lime.

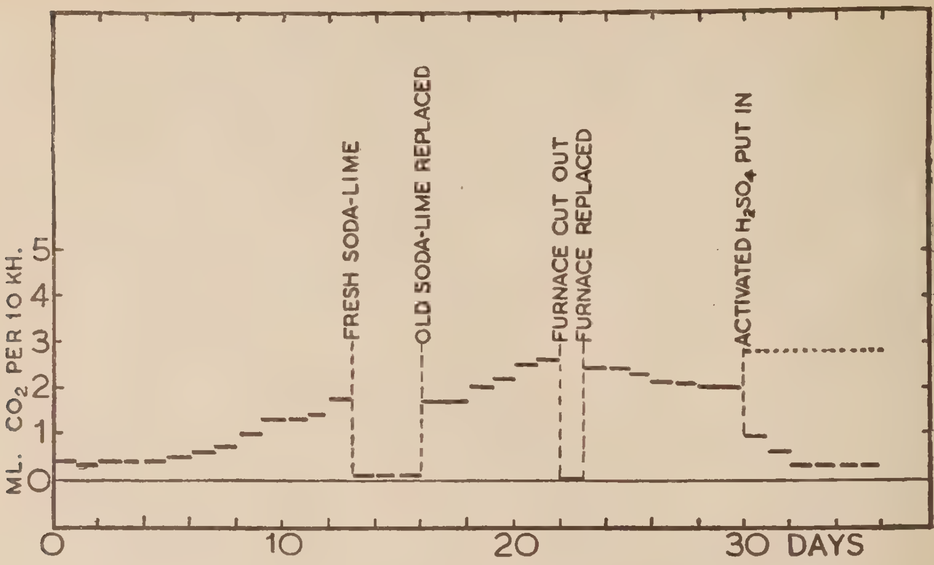
With these results in view it seemed desirable to obtain further evidence with regard to the absorption or condensation of the volatile substances by soda-lime, and to find whether they could subsequently be liberated.

EXPERIMENTAL.

The apples used in the experiments formed part of a carefully selected sample of post-climacteric Bramley's Seedling weighing about 18 kg. which were stored at 5° C. until required. Samples of 12 apples, each sample weighing about 2 kg., were used in all the experiments, which were carried out in the laboratory at a temperature of approximately 15° C. The results are expressed as ml. of CO_2 per 10 kg. per hour and are shown in Figs. 1-4.

The effect of apple volatile substances on soda-lime and their absorption in H_2SO_4 was the first investigation carried out. The sample of apples was placed in a large glass desiccator connected to a horizontal glass tube (100 × 4 cm.) filled with soda-lime and leading to a silica tube containing copper oxide heated to dull red heat in a combustion furnace. A current of CO_2-free air, of 95 per cent. humidity, was passed through the apparatus at the rate of 3 litres an hour. The CO_2 of respiration was absorbed by the soda-lime, and the CO_2 of combustion by 0·1 N NaOH which was titrated with 0·1 N HCl after addition of $BaCl_2$ solution.

Fig. 1 shows the apparent evolution of volatile substances from the apples as determined by the combustion method. It is noticeable that at the beginning, when the soda-lime was fresh, and also later when new soda-lime was put into the circuit, that the volatile substances were almost completely absorbed, and that they reverted to their original level when the old soda-lime was replaced. When the volatile substances reached an apparent maximum the

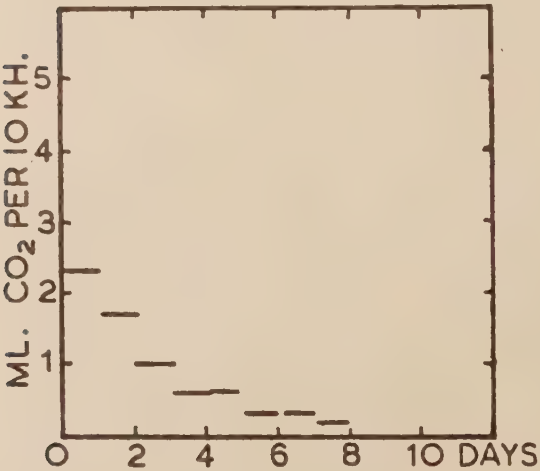


— — Combustion furnace CO_2.
. . . . . Wet combustion CO_2 of H_2SO_4.

Circuit. Air—Apples$\downarrow$Soda-lime—Furnace—CO_2.
Acid.

FIG. 1.

Absorption of volatile substances by soda-lime and by activated H_2SO_4.



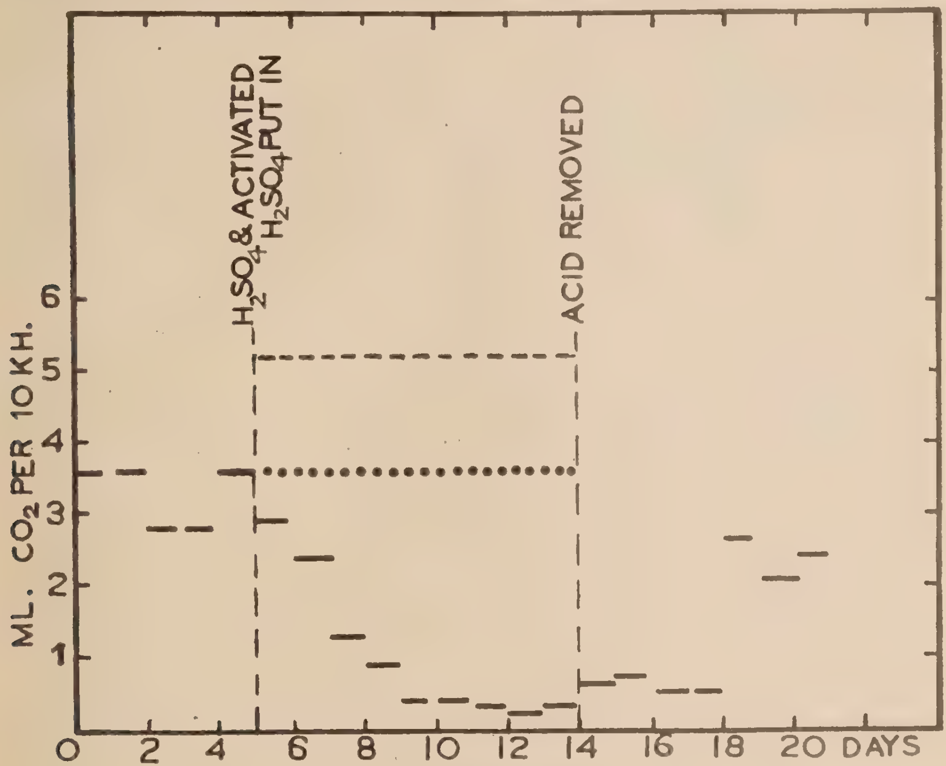
Circuit. Air—Soda-lime—Furnace—CO_2.

FIG. 2.

Volatile substances recovered from soda-lime previously saturated with them from 2 kg. apples.

furnace was cut out of the circuit, but no trace of respiration CO_2 was found, showing that the soda-lime was not allowing any CO_2 to escape.

According to Walls, all the volatile substances can be absorbed in activated H_2SO_4, hence by introducing a Truog tower containing activated H_2SO_4 between the desiccator and the soda-lime tube, the volatile substances were absorbed for a period of six days, and their total carbon content was estimated at the end of that time by the wet combustion method. Fig. 1



— — Combustion furnace CO_2
. . . . . Wet combustion CO_2 (Odorous fraction).
- - - - - Total wet combustion CO_2.
Circuit. Air—Apples ⏊ Soda-lime—Furnace—CO_2.
Acid.

FIG. 3.

Volatile substances absorbed in H_2SO_4 and activated HS_2O_4, and liberation of volatile substances from saturated soda-lime, with subsequent re-absorption on the removal of H_2SO_4.

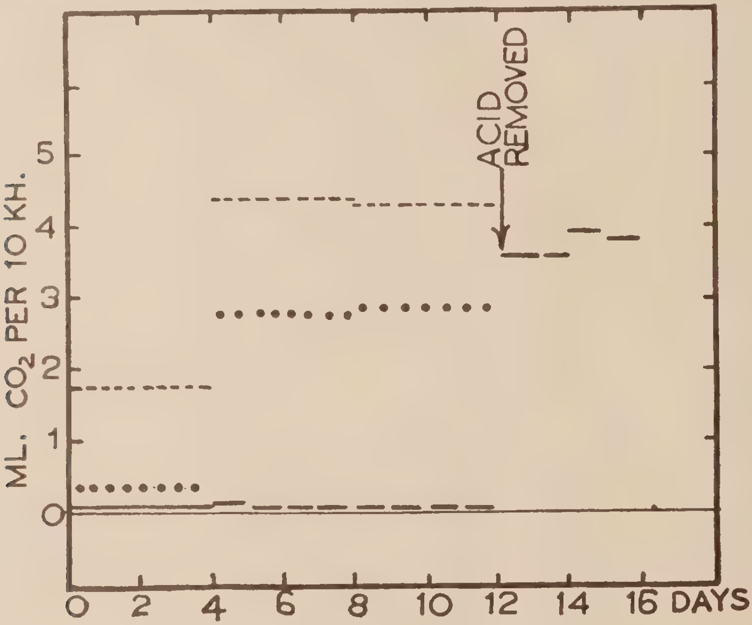
shows that the value for volatile substances by this method was slightly higher than that obtained by the furnace method.

During the absorption in activated H_2SO_4 there was a small decreasing value for furnace-combustion CO_2, which suggested that volatile substances were being liberated from the soda-lime. Therefore, a tube containing soda-lime previously saturated with the volatile substances from 2 kg. of apples was connected to the furnace and a stream of CO_2-free air was passed through it for eight days. The combustion CO_2 was determined and calculated on the weight of apples which had been used to saturate the soda-lime. Fig. 2 shows that volatile substances were liberated from the soda-lime at a diminishing rate, which confirms the results shown in Fig. 1.

For the purpose of separating the volatile substances into two fractions, two Truog towers, the first containing concentrated H_2SO_4 and the second activated H_2SO_4, were placed in the

circuit between the desiccator and the tube filled with saturated soda-lime for a period of nine days, after which the total carbon content of the sulphuric acids was determined for that period by the wet combustion method. The CO_2 had been determined for five days previously by the furnace method. Fig. 3 shows that the odorous fraction absorbed by the concentrated H_2SO_4 was approximately twice as big as the ethylene fraction absorbed by the activated H_2SO_4. During the period of absorption in H_2SO_4, the furnace-combustion CO_2 showed a gradual decrease and, after removal of the Truog towers, a gradual increase to the former level, indicating that volatile substances were liberated from the soda-lime during the nine-day period, and were subsequently re-absorbed.

The volatile substances which escaped absorption by new soda-lime were also separated into two parts by placing the two Truog towers containing (i) concentrated H_2SO_4, (ii) activated H_2SO_4, in the circuit between the soda-lime tube and the furnace. Fresh acid was placed in the towers every four days and the total carbon content determined for that period. After 12 days the towers were removed and the furnace-combustion CO_2 was noted. Fig. 4 illustrates



— — Combustion furnace CO_2.
. . . . . Wet combustion CO_2 (Odorous fraction).
- - - - - Total wet combustion CO_2.

Circuit. Air—Apples—Soda-lime $\frac{|}{\downarrow}$ Furnace—CO_2.
Acid.

FIG. 4.

Volatile substances which escape absorption by new soda-lime, trapped in H_2SO_4 and activated H_2SO_4.

these results and shows that the odorous fraction greatly increased throughout the twelve days, indicating absorption of this fraction by the soda-lime at a diminishing rate, whilst the ethylene fraction remained constant during this period and did not appear to have been absorbed.

It may be possible, however, that there was a very small but constant absorption of ethylene at the same time, hence a stream of air containing a known amount of ethylene was passed over fresh soda-lime, then through a combustion furnace, and the CO_2 determined hourly; but no evidence was obtained of any definite absorption. Then a stream of CO_2-free air was passed through this soda-lime tube and any ethylene given off was determined by combustion. A very small amount of ethylene was obtained during the first hour only; this was probably due to the ethylene that was left in the tube, as after this had been removed, no more was obtained.

SUMMARY.

1. It has been confirmed that new soda-lime absorbs the volatile substances given off by post-climacteric apples at a diminishing rate until an approximately constant value of combustion CO_2 is reached.

2. Most of the volatile substances retained by the soda-lime can be liberated by passing a CO_2-free air stream over it.

3. By using Wall's method of separating the volatile substances, it has been found that, with the particular samples of apples used, at laboratory temperature, the odorous fraction was approximately twice the ethylene value in terms of carbon.

4. Examination of the volatile substances that are not retained by new soda-lime showed that the odorous fraction accounted for the diminishing rate of absorption, whilst the ethylene fraction remained constant.

5. The total amount of carbon in the volatile substances (odorous and ethylene fractions) absorbed by H_2SO_4 and by activated H_2SO_4 was slightly greater than the total amount passing through a soda-lime tube after saturation of the soda-lime.

The work described above was carried out as part of the programme of the Food Investigation Board of the Department of Scientific and Industrial Research.

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BOOK REVIEWS

FRUIT FALL AND ITS CONTROL BY SYNTHETIC GROWTH SUBSTANCES. By M. C. VYVYAN. (Imperial Bureau of Horticulture and Plantation Crops, Technical Communication No. 18, 1946, pp. 71. Price 3s. 6d. Obtainable from Imperial Agricultural Bureaux, Central Sales Branch, Penglais, Aberystwyth.)

Growth substances are still news and once again their intelligent use promises an easing of his burden to the harassed fruitgrower. For, by applying the right growth substance, in proper concentration, at the correct time, he may now reasonably hope to retain the fruit on his trees until such time—within reason—as he himself is ready to pick it.

That there are many snares and pitfalls is not to be wondered at at this stage of a new procedure, but Dr. Vyvyan, in his survey, does much to clear up present difficulties. He first considers the whole subject of the loss of potential fruit by premature drop and its causes—environmental and inherent—and the connection of growth substances with the process of abscission. He reviews the work of widely scattered investigators, work which has concerned many different substances and fruits under widely different conditions, and deduces positive and helpful evidence from their findings and his own experience. He discusses the number and methods of applications desirable, the addition of spreaders and other supplementary substances, the use of growth substances in conjunction with other sprays and their effects on quality of fruit and habit of tree. He usefully tabulates the chief results achieved on named varieties—mainly apple—with named growth substances. Finally he makes recommendations which should be of great value to the fruitgrower. D.A.

HARNESSING THE HORMONE. By T. SWARBRICK. (Grower Publications, Ltd., London, 1946, pp. 52. Price 3s. 6d.)

Synthetic growth substances have several established uses in horticultural practice and in selecting them as the subject for No. 1 of the new " Science at Your Service " series the publishers appreciate their still greater potentialities. In this they share the enthusiasm of the author who has provided a general account of this modern development of plant physiological science as well as a helpful guide to the types of hormone product already being marketed.

Individual chapters are devoted to methods of reducing pre-harvest drop of apples and pears, of promoting the rooting of cuttings, and of producing certain fruits such as tomatoes parthenocarpically, and independently of normal pollination. In a further chapter there is a discussion of the ways in which growth substance sprays may in the future be used for avoiding or otherwise overcoming frost injury to blossom and young fruit, while reference is also made to other uses not primarily for the fruitgrower, notably as selective herbicides in weed control and for improving potato storage.

Throughout the book Dr. Swarbrick disperses his ideas on future developments of the effects of growth substances, a fact which must not be overlooked when going to it for information ; for much experimentation is essential between an idea and its widespread practical application. Nevertheless, one aim of the author is to stimulate intelligent enterprise in the use of these products of chemical synthesis, and this is facilitated by the insight thus given into the underlying principles of their action.

But in one respect one must dissent from Dr. Swarbrick, and that is in the matter of definition of the term " hormone " as applied to plants. Surely its limitation to the natural auxins, and its subordination to the omnibus term " growth regulating substance " is incompatible with the view that there are other, as yet unidentified, hormonal substances native to the plant organism. E.S.J.H.

TRACE ELEMENTS IN PLANTS AND ANIMALS. By WALTER STILES, M.A., Sc.D., F.L.S., F.R.S., Mason Professor of Botany in the University of Birmingham. (Cambridge University Press, 1946, pp. 189, 12 plates. Price 12s. 6d. net.)

This book is an excellent introduction to the subject and will be found a useful reference work for those engaged in research on trace elements.

The first chapter is devoted to a short historical introduction, a feature of which is the list of plants for the growth of which, it has been claimed, each of the elements manganese, zinc, boron, silicon, aluminium, chlorine, copper, molybdenum, tungsten and gallium are either beneficial or essential.

The second chapter describes the main methods for studying trace element problems in respect to plants. One of the most important methods consists in growing plants in a culture solution deprived of the element under study. A certain amount of each essential element is introduced in the seed or cutting of the plant. This can hardly be avoided, and it is therefore all the more necessary to reduce to an absolute minimum the amounts of the specific element that might be introduced in other ways, viz. : as an impurity in the water and salts used in preparing the culture medium and by solution from the vessels used to contain it. Methods that have been used for overcoming these difficulties are described. The growing of plants in culture solutions deprived of selected elements not only provides evidence of the essential nature of certain elements, but also gives opportunities for studying the abnormal symptoms developed by the plants when so grown, many of which are of striking appearance. Similar symptoms are often seen in the field, and these are widely used for the diagnosis of mineral deficiency, on the assumption that they are specific for the mineral deficiencies with which they are associated in solution culture.

Analysis of the plant provides another method for diagnosing mineral deficiency. Because the trace elements occur in only minute amounts in the presence of relatively large amounts of the major elements such as phosphorus, potassium and calcium, special methods of analysis are necessary. A survey of published methods is given. Even if uncritical, this is of special value to the research worker who requires a guide to the literature on this aspect but is prepared to try out the methods for himself.

Finally, deficiencies may be diagnosed by introducing elements into selected parts of plants and observing their effects in comparison with neighbouring untreated parts. The so-called "injection" methods for doing this are described briefly.

The longest chapter in the book contains descriptions of plant diseases attributable to deficiencies of manganese, zinc, boron, copper and molybdenum. These are illustrated by 12 half-tone plates. Key references to the literature are given. This chapter gives a readable and valuable survey of the subject.

The little that is known about the functions of trace elements in plants is stated briefly but clearly, and the various lines of thought on the subject are indicated.

A single chapter is devoted to trace elements in animals. First place is given to diseases due to trace-element excesses. Poisoning due to selenium and molybdenum is discussed, and diseases due to deficiencies of copper, iodine and manganese are described. An account is given of the "pining" diseases reported from Scotland, Australia and New Zealand, of all of which cobalt deficiency is a contributory cause. This chapter ends with a brief account of the functions of trace elements in animals.

The concluding remarks in the last short chapter indicate the lines along which much rapid progress is being made at present and along which the author thinks most is to be hoped for in the near future. A striking point made is that : "The realization of the importance of trace elements in plants and animals is actually very recent for, apart from a few pioneer observations, our present not inconsiderable knowledge of the subject is the result of the work done during the last 25 years, and, indeed, for the most part, during the last decade."

The book covers this rapidly expanding subject so well that it would be ungrateful to call attention to the few respects in which it might be improved.

W. A. R.

THE PRUNING OF TREES AND SHRUBS. By W. Dallimore. (Oxford, Dulau & Co., 2nd edition, 1945, pp. 99. Price 7s. 6d.)

First published about twenty years ago, and since then twice reprinted, this eminently useful little manual has now reached a second edition, in which some revision has been made and due regard paid to current views on the subject.

The author was for many years on the staff of the Royal Botanic Gardens, Kew, and the methods he advocates are those which have been practised there successfully for a long time.

The trees and shrubs included in the book are classified under the headings: deciduous ornamental; young trees, neglected broad-leaved trees; old broad-leaved trees; evergreen broad-leaved trees and conifers; park, street, woodland and hedgerow trees; flowering trees, hedges and shrubs. The pruning of fruit trees and of roses does not come within the scope of the book, as a good deal of literature is already available on these subjects.

The methods of treatment involved are clearly described, and the illustrations add to the value of the instructions given. The discussion on the proper treatment of wounds due to pruning, and of cavities resulting from decay, may perhaps be singled out as an example of the detailed and practical way in which the problems are handled in the book; and the putting into practice of the methods advocated might well be undertaken more widely than it is to-day.

There is a comprehensive alphabetical list of shrubs and climbing plants with instructions for pruning (or not pruning) each, as the case may be. This will be found particularly useful to the ordinary garden owner who is often at a loss for such specific information.

The book is one which should be in the possession of everyone who takes an interest in growing and caring for trees and shrubs; it will be found invaluable for consultation purposes when sound advice on their proper management is desired.

G.H.P.

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